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LIQUID BIOFUELS IN MONTANA - ASSESSMENT OF THE OIL SEED RESOURCE

Prepared for

MONTANA DEPAPTMENT of NATURAL RESOURCES and CONSERVATION

LIQUID BIOFUELS IN MONTANA - ASSESSMENT OF THE OIL SEED RESOURCE

Prepared by

Geneva Hammaker, Principal Investigator
Development Planning and Research Associates, Inc.
P.O. Box 727
Manhattan, KS 66502

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A. Background and Purpose

The Montana Department of Natural Resources and Conservation (DNRC) is conducting a Sustainable Energy Assessment (SEA) program to assess the potential for energy conservation and renewable energy within Montana. This report is an initial step in the research and identification of potential oil-bearing plants that may be cultivated in Montana. The ultimate goal of this portion of the state's SEA program is to alleviate problems associated with the segments of the economy depending on fossil fuels by developing oil-bearing crops whose oil can be used as diesel fuel substitutes and extenders.

This research is to identify oil-bearing plants--both oilseed and whole-plant-oil--now grown and those that can be grown in Montana. Native and naturalized plants identified as potential oil-bearing crops, but not currently grown commercially, will be sampled and tested for oil content. The most promising plants will be analyzed for such by-products as meal for livestock feed.

Further research will be conducted to determine the location and amount of land in Montana that could produce oil-bearing crops. Requirements including costs for planting, cultivating, and harvesting the near-term crops will be assessed.

B. Inventory of Montana Oil-Bearing Plants

An inventory of currently cultivated and native and naturalized Montana oil-bearing species was developed. Oilseed crops now grown in Montana include sunflower, flax, safflower, mustards, and rapeseed. Locations, yields, and other characteristics for these crops and crambe are discussed.

Two types of oil-bearing plants were included--oilseed species and whole-plant-oil species. Native and naturalized species, identified as having high oil content, were evaluated for habitat constraints and agronomic problems. Species having known constraints or problems were eliminated. The retained annual and perennial oilseed and whole-plant-oil species are listed in Tables 1-3. Most of these species were ultimately collected and analyzed for oil content and feed components.

C. Plant Sampling, Testing and Results

Potential sampling sites were selected prior to actual sampling and four major collecting trips within the area from the Rocky Mountain front (Bozeman to Shelby) east to Miles City planned. Actual sampling sites were selected as species were located during each trip. Three sites for each species were selected when possible; fewer sites were located for some uncommon species. More sites were sampled when either few plants per site or few plants in collectable condition per site were found. For these, samples from several sites were combined to obtain a large enough sample for analysis.

Plants for collection were selected randomly. Seed (or fruit) samples were collected only from mature plants. Whole plant samples of mature plants (slightly before seed disposal) were obtained by cutting the plants at ground level. Seed and whole plant samples were further prepared at Montana State University by seed cleaning (e.g., thrashing, air separation) for seed samples and by drying and grinding for whole plant samples. The prepared samples were then shipped to Doty Laboratories, Inc. of North Kansas City, Missouri for seed and whole plant analyses.

Analyses included oil content and tests to examine feed quality, i.e, protein, carbohydrates, fiber, and total digestible nutrients. The feed quality tests were run only if the oil content was above 20 percent seed-oil or 3 percent whole-plant-oil.

Tables 4 (oilseed species) and 5 (whole-plant-oil species) present the analysis results.

Investigated species were next placed into priority groupings for further research. Placement was based principally on oil content, but feed quality, toxicity and field observations on agronomic potential were considered as well. The priority groupings, for the potential oilseed and whole-plant-oil species examined, are presented in Tables 6 and 7, respectively. Included in these tables, for each species, is a brief explanation (the comments column) of the grouping for each species.

D. Adaptable Oil-Bearing Plants

Promising, oil-bearing, nonnative plants were examined and their ability to adapt to Montana conditions was assessed. Plants, which have become well known for their oil producing capabilities, as well as, nonnative mustards grown previously in Montana were investigated.

Species with the greatest near-term potential in Montana are rapeseed (Brassica napus and B. campestris) and crambe (Crambe abyssinica). The first is already cultivated in Canada and likely could be readily adapted to Montana, especially in the more western and northern areas with cool July's. Crambe, though not commercially grown, has been shown to produce good yields in Montana, provided it is planted early in the season.

Members of the Lesquerella (Bladderpod) genus may have potential in Montana, however, realization of their potential is probably much longer term than crops currently grown.

Other popularized species such as Jojoba, Buffalo Gourd, Money Plant, Caster, Meadowfoam, Gopher Weed, Chinese Tallow Tree, and Stokes' Aster have habitat constraints (e.g., growing season length, temperature and moisture requirements) that would make them difficult (or impossible) to adapt to cultivation in Montana.

E. Soils for Oil Crop Production

Soil associations and land cover were examined for cropping potentials. Major areas of soils suitable for crop production were

located and their potential stratified from soil mapping units (Figure 1). Eighty-five percent of the state's approximately 16.3 million dryland crop acres and nearly 13 million acres of rangeland were identified. It is on this land base that oil-bearing plant production could occur. Of the acreage of current importance (Group 1), oil crop production could take place on the cultivated portions (9.4 million acres). Uncultivated portions (5.1 million acres) now in rangeland are prime candidates for expansion. The 3.4 million cropland acres in Group 2, soils of secondary importance, are lower in productivity or have restrictions to cropping. The 3.4 million acres of Group 2 currently used for rangeland have more severe restrictions and would provide limited potential for oil crop production.

Group 3 soils have limited potential for cultivation and are primarily suited for permanent vegetative cover. These lands are fragile and, if cultivated, the erosion hazard is severe.

Since little information is available concerning the soil and climatic adaptation of the plants sampled in this study, comparison will need to be drawn from the information provided for crops currently grown for oil in Montana--safflower, sunflower, flax, mustards and rapeseed.

F. Crop Budgets

The economics of cultivating oilseed crops suitable for Montana soil and climatic conditions were examined using crop budgets. Crop budgets showing revenues, variable costs, fixed costs and net gain (or loss) were prepared for flax, sunflower, safflower, rapeseed, mustard, and crambe.

In order to compare the economics of producing oilseed crops with that of small grains, similar crop budgets were also prepared for wheat and barley. A summary of the revenues, costs and profits is shown in Table 8.

G. Montana Distillate Fuel Consumption and Vegetable Oil Replacement

Distillate fuel oil consumption in Montana during 1980 and 1981 averaged approximately 275 million gallons annually. Primary users are listed below.

Users	Annual Quantity 1981	1980
	million gallons	
On-highway	100.1	97.2
Railroad	61.1	77.3
Farm	38.1	32.3
Commercial	16.0	12.7
Industrial	16.0	10.1
Oil Company	13.1	6.4
Residential	11.5	15.7
Off-highway	7.7	16.1
Other	8.8	10.5
Total	272.4	278.3

Source: Energy Information Administration, USDOE, Petroleum Supply Annual 1981 Vol 1, U.S. Government Printing Office, July 1982.

The volume of vegetable oil needed to replace a gallon of distillate fuel is uncertain. However, by making the assumption that a gallon of diesel fuel can be replaced by 1.05 gallons of sunflower oil (based on research of fuel consumption and power output by Bettis, et al., 1982), sunflower acreages sufficient to grow enough oil to replace all distillate fuel can be estimated. Given an average sunflower oil yield of 65 gallons per acre, approximately 4,442,000 acres of sunflowers could produce enough oil to replace the distillate fuel used in Montana. This is approximately 280 times larger than the current Montana sunflower acreage and 1.5 million acres less than the

current Montana wheat acreage. To replace the 1981 farm and railroad diesel fuel with sunflower oil would require approximately 1.6 million acres of sunflower.

H. Feasibility Indicators and Impacts

Under current conditions, the economics of producing oilseed crops already frequently grown in Montana compare closely to wheat and barley. However, the costs of producing a gallon of vegetable oil do not compare favorably with the cost of diesel fuel. Costs for producing vegetable oils range from approximately $2 to $4 per gallon compared to diesel fuels prices which are $1 per gallon. Vegetable oil could, however, become quite attractive as a diesel fuel substitute or extender if diesel fuel supplies should become unavailable. In particular, vegetable (plant) oils could now be used in railroad and agricultural diesel equipment in an emergency.

Many other factors are likely to be of some importance in the event of widespread cultivation of oilseed and whole-plant-oil crops as a fuel source. These factors include modifications to the farming operation such as additional equipment requirements, impacts on soils and impacts on food prices which result from growing oilseed crops for fuel. These factors cannot accurately be estimated quantitatively at this time; their magnitude would be determined by the type of substitute fuel program developed.

I. Conclusions

Conclusions resulting from the study are.

- Twenty-two native or naturalized perennials and sixteen annuals show potential as seed oil plants.
- Twenty-seven native or naturalized species show good potential as whole-plant-oil plants.
- Seven native or naturalized species, Prickly Poppy, Snow-on-the-Mountain, Spatula-leafed Spurge, Small-flowered Gaura, Dyer's Woad, Prairie Sunflower and Jim Hill (or Tumble) Mustard, show high potential for seed oil.

- Five native or naturalized species, Rubber Rabbitbrush, Field Sagewort, Showy Milkweed, Curly-cup Gumweed, and Stiff Goldenrod, show high potential for whole-plant oil, with Rubber Rabbitbrush showing the greatest potential.
- Problems could occur with some of the promising species that are now considered weeds.
- Crambe and Rapeseed offer potential for near term cultivation in Montana.
- Members of the Lesquerella genus (Bladderpod) offer longer term potential for adaptation to cultivation in Montana.
- The well publicized oil-bearing species, e.g. Jojoba, Buffalo Gourd, Gopher Weed, Money Plant and Castor, have habitat constraints that make them difficult or perhaps impossible to adapt to cultivation in Montana.
- The 16 million acres of soils already extensively utilized for dryland crop production are likely to be used for oil crop production, if these are economically competitive.
- Oil crop production could also occur on 20 to 30 percent of the 13 million acres of rangeland associated with the cultivated areas, if special precautions are taken to control erosion.
- The economics of oilseed crop production compare favorably today with that of wheat and barley.
- The agricultural, other economic, and environmental impacts of producing plant oils for fuel depend on the type and extent of the program developed.
- The feasibility of producing plant oils for diesel fuel in an emergency situation will be determined by the value placed on preserving the productivity of the dependent economic segments.

Figure 1. Selected Soil Associations

Table 1. Native and naturalized Montana annuals retained as potential oilseed plants after preliminary habitat and agronomic examination

Family	Species	Common name	Habitat 2/
Asteraceae	Helianthus petiolaris	Prairie Sunflower	Sandy oil and waste places
	Xanthium strumarium	Cocklebur, Cow Cockle	Fields and waste places
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	Fields and waste places
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	Disturbed areas
	Descurainia pinnata	Tansymustard	Sandy soil
	D. sophia	Flixweed	Waste areas
	Isatis tinctoria 1/	Dyer's Woad, Yellow Woad	Roadsides
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	Waste places
	S. loeselii	Loesel Tumble Mustard	Waste places and oil fields
	Thlaspi arvense	Field Pennycress, Fanweed	Fields and roadsides
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	Plains and roadsides
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	Wastelands
Euphorbiaceae	Euphorbia marginata	Snow-on-the-Mountain	Dry plains and valleys
	E. spathulata	Spatula-leaved Spurge	Sand spots or openings in grasslands
Onagraceae	Gaura parviflora 1/	Small-flowered Gaura	Gravelly or sandy soil
Papaveraceae	Argemone polyanthemos	Prickly Poppy	Plains

1/ Annual or biennial

2/ W. E. Booth and J. C. Wright, Flora of Montana, Part II, (Bozeman, Montana. Montana State University 1966); T. Van Bruggen, The Vascular Plants of South Dakota, (Ames, Iowa: Iowa State University Press, 1976).

Source: Development Planning and Research Associates, Inc.

Table 2. Native and naturalized Montana perennials retained as potential oilseed plants after preliminary habitat and agronomic examination

Family	Species	Common name	Habitat 2/
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	Stream banks, moist meadows
	A. syriaca	Common Milkweed	Fields and waste places
Asteraceae	Achillea millefolium	Yarrow	Plains and mountain valleys
	Artemisia campestris 1/	Field Sagewort	Rocky or sandy places
	A. frigida	Fringed Sagewort	Prairies and plains
	A. ludoviciana	Cudweed Sagewort	Grasslands and dry lawns
	Echinacea pallida	Pale Purple Coneflower	No habitat given
	Helianthus maximilianii	Maximilian Sunflower	Prairies and plains
	Kuhnia eupatorioides	False Boneset	Dry hillsides and prairies
	Liatris punctata	Dotted Blazingstar	Grasslands
Brassicaceae	Lesquerella alpina	Alkaline Bladderpod	Mountain slopes and plains
	L. ludoviciana	Silvery Bladderpod	Rocky slopes of hills and plains
	Stanleya pinnata	Bushy Stanleya	Dry grasslands
	S. viridiflora	Perennial Stanleya	Dry hills
	Thelypodium integrifolium 1/	Entireleaved Thelypody	Grasslands
	T. laciniatum 1/	Thickleaved Thelypody	Grasslands
Euphorbiaceae	Euphorbia esula	Leafy Spurge	Field and range weed
Linaceae	Linum perenne	Wild Blue Flax	Grasslands
Loasaceae	Mentzelia decapetala 1/	Tenpetal Blazingstar, Sand Lily	Canyons and roadcuts in gravel
	M. dispersa	Scattered Stickleaf	Dry sandy or gravelly soils
	M. laevicaulis	Fivepetal Blazingstar	Gravelly or sandy soil
	M. nuda 1/	Plains Evening-Star	Gravelly or sandy soil

1/ Biennial to perennial

2/ W. E. Booth and J. C. Wright, Flora of Montana, Part II, (Bozeman, Montana. Montana State University 1966); T. Van Bruggen, The Vascular Plants of South Dakota, (Ames, Iowa: Iowa State University Press, 1976).

Source: Development Planning and Research Associates, Inc.

Table 3. Native and naturalized Montana species retained as potential whole-plant-oil species

Family	Species	Common name	Habitat 1/
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	Moist meadows
	A. syriaca	Common Milkweed	Fields and waste places
	A. verticillata	Whorled Milkweed	Dry soil
	A. viridiflora	Green Milkweed	Prairie, sandy soil
Asteraceae	Achillea millefolium	Yarrow	Plains and mountain valleys
	Artemisia campestris	Field Sagewort	Rocky or sandy places
	A. ludoviciana	Cudweed Sagewort	Grasslands and dry lands
	Carduus nutans	Musk Thistle	Grasslands
	Chrysothamnus nauseosus	Rubber Rabbitbrush	Grasslands
	C. viscidiflorus	Green Rabbitbrush	Dry hills and plains
	Cirsium arvense	Canada Thistle	A troublesome weed
	C. undulatum	Wavyleaf Thistle	Dry plains
	Grindelia squarrosa	Curly-cup Gumweed	Moist places
	Gutierrezia sarothrae	Broom Snakeweed	Open rangeland
	Liatris punctata	Dotted Blazingstar	Grasslands
	Solidago rigida	Stiff Goldenrod	Dry prairie and plains
	Tragopogon dubius	Common Salsify	Roadsides, open places or in bunch grass rangelands
Caprifoliaceae	Symphoricarpos orbiculatus	Coralberry	Open woods, thickets, dry banks
Chenopodiaceae	Chenopodium album	Lambsquarter, White Goosefoot	Waste places
	Kochia scoparia	Kochia, Summer Cypress	Wasteland weed
	Salsola kali	Russian Thistle	Dry valleys and plains
Euphorbiaceae	Euphorbia esula	Leafy Spurge	Field and range weed
	E. marginata	Snow-on-the-Mountain	Dry plains and valleys
	E. spathulata	Spatula-leaved Spurge	Sand spots or openings in grasslands
Gramineae	Agropyron repens	Quack Grass	Roadsides
	Elymus canadensis	Canada Wildrye	Prairies and roadsides
Papaveraceae	Argemone polyanthemos	Prickly Poppy	Plains

1/ W. E. Booth and J. C. Wright, Flora of Montana, Part II, (Bozeman, Montana. Montana State University 1966): T. Van Bruggen, The Vascular Plants of South Dakota, (Ames, Iowa: Iowa State University Press, 1976).

Source: Development Planning and Research Associates, Inc.

Table 4. Seed-analysis results for potential oilseed species 1/

Family	Species	Common name	Site identification number	Percentages: Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash	Plant part analyzed
Asteraceae	Helianthus petiolaris	Prairie Sunflower	No sites located	-	-	-	-	-	-	--
	Xanthium strumarium	Cocklebur, Cow Cockle	23	10.0	-	-	-	-	-	Seed and pericarp
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	7, 12	18.2	-	-	-	-	-	Seed
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	Multiple 4/	24.6	27.6	43.9	126.9	17.4	3.9	Seed
			21	23.3	26.2	47.8	126.4	37.7	2.7	Seed
	Descurainia pinnata	Tansymustard	No sites located							
	D. sophia	Flixweed	No sites located							
	Isatis tinctoria	Dyer's Woad, Yellow Woad	No sites located							
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	15	28.4	34.7	33.2	131.7	7.9	3.7	Seed
			28	32.2	29.8	33.9	136.2	7.8	4.1	Seed
	S. loeselii	Loesel Tumble Mustard	1	27.9	29.5	39.8	131.9	14.9	2.9	Seed
			4	35.6	31.1	30.1	141.5	5.3	3.1	Seed
			15	17.7	30.3	48.7	118.6	35.2	3.5	Seed
	Thlaspi arvense	Field Pennycress, Fanweed	13	24.0	26.6	43.7	124.3	10.0	5.7	Seed
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	11	23.3	23.5	49.8	125.7	32.3	3.4	Seed
			22	18.8	-	-	-	-	-	Seed
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	1	8.2	-	-	-	-	-	Seed
Euphorbiaceae	Euphorbia esula	Leafy Spurge	No sites located							
	E. marginata	Snow-on-the-Mountain	24	25.6	17.6	51.7	126.9	23.5	5.1	Seed
	E. spathulata	Spatula-leaved Spurge	No sites located							

Continued...

Table 4. (Continued)

Family	Species	Common name	Site identification number	Percentages: Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash	Plant part analyzed
Loasaceae	Mentzelia decapetala	Tenpetal Blazingstar, Sandy Lily	29,30	28.5	19.0	39.0	122.1	17.3	13.5	Seed
Onagraceae	Gaura parviflora 2/	Small-flowered Gaura	No sites located							
Papaveraceae	Argemone polyanthemos	Prickly Poppy	18,19,20	36.0	17.4	41.6	140.0	11.7	5.0	Seed

1/ All data were calculated on a dry weight basis. When oil content was below 20 percent, no other tests were run.

2/ Includes fiber and nitrogen-free extract.

3/ T.D.N. - total digestible nutrients. Following procedures of Doty Laboratories, Inc., we assumed no digestibility coefficients in calculating T.D.N. (i.e., T.D.N. = 2.25 x oil (%) + carbohydrates (%) + protein (%)). Thus, this T.D.N. expresses the total potential nutrients available in the seed.

4/ Includes sites 3, 4, 7, 8, 9,and 16.

Source: Research by Development Planning and Research Associates, Inc.

Table 5. Plant analysis results for potential whole-plant-oil species. 1/

Family	Species	Common name	Site identification number	Percentages					
				Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	29	5.7	11.6	74.8	99.2	40.9	7.9
			39	6.1	10.5	70.9	95.1	24.7	12.5
			40	6.2	10.9	74.3	99.2	22.9	8.5
	A. syriaca	Common Milkweed	No sites located	-	-	-	-	-	-
	A. verticillata	Whorled Milkweed	No sites located	-	-	-	-	-	-
	A. viridiflora	Green Milkweed	No sites located	-	-	-	-	-	-
Asteraceae	Achillea millefolium	Yarrow	Plants not in collectable condition	-	-	-	-	-	-
	Artemisia campestris	Field Sagewort	32	6.9	5.7	82.6	103.8	38.8	4.7
			38	5.6	5.1	83.1	100.8	35.8	6.2
	A. ludoviciana	Cudweed Sagewort	34	3.8	4.7	87.0	100.3	40.1	4.5
			34	5.1	13.7	74.9	100.1	30.9	6.4
			40	2.6	-	-	-	-	-
	Carduus nutans	Musk Thistle	17	1.7	-	-	-	-	-
			26	3.7	9.0	75.6	92.8	36.2	11.7
			27	2.2	-	-	-	-	-
	Chrysothamnus nauseosus	Rubber Rabbitbrush	30	8.7	8.7	77.7	106.0	30.0	4.9
			31	8.0	8.1	79.6	105.7	35.1	4.4
	C. viscidiflorus	Green Rabbitbrush	No sites located	-	-	-	-	-	-
	Cirsium arvense	Canada Thistle	2	2.5	-	-	-	-	-
			10	4.6	8.7	76.9	96.0	31.6	9.8
			28	3.4	8.8	75.6	92.1	32.9	12.2
	C. undulatum	Wavyleaf Thistle	32	5.5	7.4	79.2	98.9	34.5	7.9
	Grindelia squarrosa	Curly-cup Gumweed	32	13.1	8.2	68.6	106.3	27.1	10.1
			33	10.0	7.6	73.5	103.6	34.6	8.9
			38	10.7	12.5	67.5	104.1	31.8	9.3
	Gutierrezia sarothrae	Broom Snakeweed	28	7.8	7.3	66.6	91.5	22.0	18.3
			35	6.4	6.6	68.2	88.3	25.2	18.9
			41	7.6	10.6	64.9	92.6	25.2	16.9

Continued....

Table 5. (Continued)

Family	Species	Common name	Site identification number	Percentages					
				Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash
	Liatris punctata	Dotted Blazingstar	35	5.3	6.2	80.0	98.0	36.0	8.5
			36	5.2	6.4	80.0	98.1	35.9	8.4
	Solidago rigida	Stiff Goldenrod	34	8.3	5.4	80.2	104.3	30.3	6.1
			35	8.1	6.5	79.1	103.8	29.5	6.4
			36	8.9	5.7	78.6	104.3	27.1	6.7
	Tragopogon dubius	Common Salsify	30	5.0	5.3	80.5	97.1	30.3	9.3
			33	5.2	5.4	79.6	96.7	39.7	9.8
Caprifoliaceae	Symphoricarpos orbiculatus	Coralberry	No sites located	-	-	-	-	-	-
Chenopodiaceae	Chenopodium album	Lambsquarter, White Goosefoot	Seeds already dispersed	-	-	-	-	-	-
	Kochia scoparia	Kochia, Summer Cypress	4	3.1	12.9	72.9	92.8	28.6	11.1
			38	3.8	12.8	73.3	94.7	28.5	10.0
			39	2.7	12.8	74.2	93.1	32.8	10.3
	Salsola kali	Russian Thistle	39	5.3	10.8	67.6	90.3	27.4	16.4
			41	4.7	6.9	73.8	91.3	31.7	14.9
Euphorbiaceae	Euphorbia esula	Leafy Spurge	2	4.9	7.6	78.3	96.9	37.3	9.2
	E. marginata	Snow-on-the-Mountain	24	4.7	9.7	72.7	93.0	29.8	12.9
	E. spathulata	Spatula-leaved Spurge	No sites located	-	-	-	-	-	-
Gramineae	Agropyron repens	Quack Grass	27	2.2	-	-	-	-	-
			28	2.8	-	-	-	-	-
	Elymus canadensis	Canada Wildrye	Seeds already dispersed	-	-	-	-	-	-
Papaveraceae	Argemone polyanthemos	Prickly Poppy	19	1.9	-	-	-	-	-

1/ All data are calculated on a dry weight bases. When oil content was below 3 percent, no other tests were run.

2/ Includes fiber and nitrogen-free extract.

3/ T.D.N. - total digestible nutrients. We assumed no digestibility coefficients in calculating T.D.N. (i.e., T.D.N. = 2.25 x oil (%) + carbohydrates (%) + protein (%)). Thus, this T.D.N. expresses the total potential nutrients available in the seed.

Source: Development Planning and Research Associates, Inc.

Table 6. Preliminary priority grouping of native and naturalized species considered potential oilseed crops

Priority grouping	Species	Common name	Comments
High interest	Argemone polyanthemos	Prickly Poppy	Oil levels are very high and seed nutritional levels appear good. Concerns are seed yields and possible toxins in the meal.
High interest	Euphorbia marginata	Snow-on-the-Mountain	Oil and nutrient levels make species attractive as an oil seed plant but the seed meal's potential toxicity should be examined carefully.
High interest	Euphorbia spathulata	Spatula-leafed Spurge	No seed-analysis data are available for this species. Because of high oil and protein levels associated with the Euphorbia genus, it definitely should be examined further. Reasons for this species rareness in Montana should be examined carefully and the potential toxicity of its seed meal.
High interest	Gaura parviflora	Small-flowered Gaura	Oil and protein data from secondary sources warrant further research. Reasons for the species rareness in Montana should be examined carefully.
High interest	Isatis tinctoria	Dyer's Woad	Oil and protein data from secondary sources indicate that this species should be examined further. Moisture requirements should be examined because they could be too high for dryland farming.
High interest	Helianthus petiolaris	Prairie Sunflower	Secondary sources indicate good oil levels, but below other species in this priority grouping.
High interest	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	This species' high oil levels give it a high priority for further research. Toxicity characteristics should be examined carefully.
Medium interest	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	Medium oil levels, and high protein levels. Shattering could be a problem. Seed meal contains a toxin that can be removed with proper processing.
Medium interest	Descurainia pinnata	Tansymustard	Secondary sources indicate very high oil and protein levels, but plants tend to be small, indicating potential yield problems. Unknown toxin associated with species may cause feeding problems.
Medium interest	Descurainia sophia	Flixweed	Secondary sources indicate very high oil and protein levels, but plants tend to be small, indicating potential yield problems. Unknown toxin associated with species may cause feeding problems.

Continued....

Table 6. (Continued)

Priority grouping	Species	Common name	Comments
Medium interest	Mentzelia decapetala	Tenpetal Blazingstar, Sand Lily	Oil level is high but, shattering and indeterminant pod development could be a problem. Seeds have special structures for wind dispersal and are readily lost from the pods. Seeds are small and yields appear low relative to total plant weight. Seeds mature very late in season, so losses can result due to freezing.
Medium interest	Sisymbrium loeselii	Loesel Tumble Mustard	Though the oil levels of this species can be very high, its severe shattering problem will make cultivating this species difficult.
Medium interest	Xanthium strumarium	Cocklebur, Cow Cockle	Though oil and protein levels are potentially quite high 1/, possible seed handling problems and high seed meal toxicity should be examined carefully.
Low to medium interest	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	Oil content falls in the low to medium range of species examined. Indeterminant pod productions, shattering, and insect predation are of concern. Feed quality appears good.
Low to medium interest	Euphorbia esula	Leafy Spurge	Though oil content are potentially quite high, eradication problems make this species of less interest.
Low interest	Brassica kaber	Wild Mustard, Charlock	Oil levels are low. Plants are small and water requirements may restrict where they can grow.
Low interest	Kochia scoparia	Kochia, Summer Cypress	Low oil levels and potential problems with allelopathy make this species of low interest. It contains several toxins.
Low interest	Thlaspi arvense	Field Pennycress, Fanweed	Oil levels do not appear high enough to balance difficulties caused by plant's small size and apparent toxicity.

1/ We analyzed the seed and pericarp and resulting oil and protein levels were very low. Secondary sources analyzed seed only. Results indicate high oil and protein levels.

Source: Development Planning and Research Associates, Inc.

Table 7. Preliminary priority grouping of native and naturalized species considered as potential whole-plant-oil plants

Priority grouping	Species	Common name	Comments
High interest	Chrysothamnus nauseosus	Rubber Rabbitbrush	Oil content is high. No apparent toxicity and agronomic problems. Plants respond well to multiple clippings.
Medium to high interest	Artemisia campestris	Field Sagewort	Oil content is in the lower portion of the high range. Plants may be short on the driest sites.
Medium to high interest	Asclepias speciosa	Showy Milkweed	Oil content is in the lower portion of the high range. Moisture requirements may restrict production area.
Medium to high interest	Grindelia squarrosa	Curly-cup Gumweed	Oil content is extremely high, but small stature may make yields inadequate. Plants tend to accumulate selenium when it is present in the soil.
Medium to high interest	Solidago rigida	Stiff Goldenrod	Oil content is high, but plants may be too short on drier sites to provide adequate yields without irrigation. Toxicity at flowering time should be examined.
Medium interest	Cirsium undulatum	Wavyleaf Thistle	Oil content is in mid range of species examined. Feed quality appears good though care must be taken in processing because plants have spines.
Medium interest	Euphorbia marginata	Snow-on-the-Mountain	Oil levels are in the mid range of species studied. Toxicity should be examined carefully.
Medium interest	Gutierrezia sarothrae	Broom Snakeweed	Though oil levels are high, plants are small and yields may not be adequate. Plants accumulate selenium when it is present in soil. Feed nutritional levels are not as high as other species examined.
Medium interest	Salsola kali	Russian Thistle	Oil content is in the medium range of species sampled. Feed nutritional levels are not as high as other species examined. Potential toxicity problems should be investigated carefully.
Medium interest	Tragopogon dubius	Common Salsify	Oil content is in the medium range of species examined. Protein levels are low. No known toxicity and agronomic problems.
Low to medium interest	Artemisia ludoviciana	Cudweed Sagewort	Oil content is in the medium range of species sampled. Plants may be short on driest sites.
Low to medium interest	Carduus nutans	Musk Thistle	Oil content is in the low to medium range. Due to nitrates in plant meal, care must be taken when feeding to animals. Feed must be processed carefully because plants have spines.
Low to medium interest	Liatris punctata	Dotted Blazingstar	Though oil content is in the mid range of species examined, plants tend to be small and yields may be inadequate.

Continued....

Table 7. (Continued)

Priority grouping	Species	Common name	Comments
Low interest	*Agropyron repens*	Quack Grass	Low oil levels and problems eradicating after cultivation give this species low priority for further study.
Low interest	*Argemone polyanthemos*	Prickly Poppy	Oil content was the lowest of any species examined. Plant meal may have toxicity problems.
Low interest	*Cirsium arvense*	Canada Thistle	Oil levels are not high enough to balance potential eradication and toxicity problems.
Low interest	*Euphorbia esula*	Leafy Spurge	Oil content is in mid range of species examined, but potential eradication problems make this plant of low interest.
Low interest	*Kochia scoparia*	Kochia, Summer Cypress	Oil content is in the low to medium range. Plants have potential allelopathy and toxicity problems.

Source: Development Planning and Research Associates, Inc.

Table 8. Comparison of economics of producing oilseed and small grain crops

Crop	Costs	Revenues	Profits	Profits omitting land costs
	($/acre)			
Wheat	159.13	140.58	-18.55	21.45
Barley	160.54	116.55	-43.99	-3.99
Flax	140.10	92.04	-48.06	-8.06
Sunflower	168.51	98.64	-69.87	-29.87
Safflower	157.93	129.00	-28.93	11.07
Rapeseed	143.22	106.20	-37.02	2.98
Yellow mustard	143.29	79.92	-63.37	-23.37
Crambe	151.06	No market	--	--

Source: Summary of Tables VII-1 to VII-8.

LIQUID BIOFUELS IN MONTANA

ASSESSMENT OF THE OIL SEED RESOURCE

I. INTRODUCTION

A. Background

The American economy in recent years has faced increasing costs and limited supplies of conventional petroleum fuels. This situation stirred interest in producing liquid fuels from agricultural products that might insure a continuous supply of fuel. Research on agriculturally based fuels has concentrated on alcohol to be added to gasoline and usually marketed as a high octane, unleaded fuel, primarily for automobiles. Unfortunately, for those energy-intensive that require diesel engines, major engine modifications are required for alcohol use (Peterson, et al., 1980).

In addition to on-highway use, diesel engines are widely used by the railroads and in agricultural crop production. Substitutes or extenders for diesel fuel are needed to insure the availability of fuel for these operations.

The use of neat vegetable oil and blends is being studied for medium-speed diesel engines by U. S. DOE, the Federal Railroad Administration, and the Association of American Railroads. Medium-speed diesels are used for railroad transportation and electric power generation. The research involves engine testing of neat sunflower oil and blends in 12-cylinder diesels. These studies conducted by Southwest Research Institute (SwRI) San Antonio, Texas indicate that vegetable oil is an acceptable fuel in medium-speed engines and is ready for commercial development.

Research at North Dakota State University and the University of Idaho concluded that dryland-production regions could produce the liquid fuel necessary for crop production by diverting approximately 10 percent of total crop acreage to a vegetable oilseed crop (Hofman, et al., 1980 and Peterson, et al., 1980). Economic analyses in both those reports

showed that refined vegetable oils now cost more than diesel fuel, but that may not be true in the future. Although price increases for fuel have moderated recently, it is somewhat doubtful that prices will stabilize in the long run. In short, if the price of petroleum-derived fuels rises more rapidly than the price of oilseed crops, vegetable oil may become a feasible diesel fuel substitute.

But more important than a less expensive fuel is the need to develop alternative sources, which could become crucially important with a sudden decrease in diesel fuel's availability. A worldwide petroleum embargo now could be disastrous to the dependent economic sectors, drastically reducing production. So even the development of an expensive vegetable oil fuel could reduce dependence on imported oil and potential problems with sudden decreases in diesel fuel supply.

In addition to the prospect of vegetable oil becoming economic from increases in conventional diesel fuel prices, increased yields of vegetable oilseed crops could make vegetable oils less expensive. Recent breakthroughs in plant breeding in sunflowers, for example, have dramatically increased oil yields. Similar breakthroughs have occurred in safflower and in Canadian rapeseed (Canola). Other possibilities include developing new oilseed crops or using some not presently cultivated.

B. Purpose and Scope

The Montana Department of Natural Resources and Conservation (DNRC) is conducting a Sustainable Energy Assessment (SEA) program to assess the potential for energy conservation and renewable energy within Montana. This report was an initial step in the research and identification of potential oil-bearing plants that may be cultivated in Montana. The ultimate goal of this portion of the state's SEA program is to alleviate problems associated with the economic sectors depending on fossil fuels by developing oil-bearing crops whose oil can be used as diesel fuel substitutes and extenders.

This research identified oil-bearing plants now grown and those that could be grown in Montana. Native plants identified as potential

oil-bearing crops, but not currently grown, were sampled and tested for oil. The most promising plants were analyzed for such by-products as meal for livestock feed, biomass for combustion, and for other by-products.

Research was conducted to determine the location and amount of land in Montana that could produce oil-bearing crops. Requirements including costs for planting, cultivating, and harvesting the near-term crops as well as optimal crop rotations were assessed.

C. Time Frame

Research identifying potential oil-bearing crops in Montana began in late summer, 1982, and was completed in November 1982. Unfortunately, such a short time prevented sampling some potential oilseed crops because their seeds were dispersed before sampling could begin.

This research included an analysis of crop budgets and yields, but the data were at best tenuous for crops not currently grown and those lacking adequate experimental plot tests. Additionally, experience with other plants makes it reasonable to expect that yields from wild plants can be greatly increased by genetic selection or by chemical growth stimulation. Problems such as seed shattering, lack of flowering or seed setting, disease or poor upright growth habit need to be overcome through breeding and selection. While testing designed to enhance the genetic properties of any plants is beyond the scope of this study, such testing is crucial. Attempts to do anything other than identify the plants and test the oil content and oil and by-product characteristics are futile without extensive plant breeding and yield tests.

II. INVENTORY OF MONTANA OIL BEARING PLANTS

Of the oilseed crops grown throughout the contiguous United States soybeans are most prominent, planted on approximately 70 million acres in 1980. Other 1980 U.S. oilseed crop acreages planted were cotton, approximately 14 million acres; sunflowers, 4 million acres; peanuts 1.5 million acres; and flax 0.8 million acres. Other oil crops important in certain areas of the U.S. included tung, safflower, rapeseed, jojoba, mustard, castor, sesame, palm, olive, and copra.

Oilseed crops now grown in Montana include mustard, rapeseed, safflower, sunflower, and flax. Locations, yields, and other characteristics of these crops follow. Soybeans, grown infrequently in Montana, are generally considered to be adapted to warmer climates and are not considered here.

A. Oilseed Species Currently Cultivated in Montana

Acres planted to the five major oilseed crops vary widely from year to year, with acreages planted any given year depending heavily on such federal programs as crop set aside and price support programs. Of course, prices (and price expectations) for the oilseed crops as well as other small grains grown in the area influence the acres planted any year. For example, high prices for a crop one year nearly always increase acreage of that crop the next year.

Because few of the oilseed crops have been considered important, comprehensive data are not always available. The available data on acreages, yields, prices, and locations of plantings are summarized in Table II-1 for each of Montana's oilseed crops.

Table II-1. Plantings, location of plantings, yields, and prices for oilseed crops currently grown in Montana

Oilseed crop	1980 Plantings U.S.	1980 Plantings Montana	Primary locations of plantings U.S. (States)	Primary locations of plantings Montana (Crop reporting dist.)	Average yields	October 1982 price received by Montana farmers
	(1000 acres)				(cwt/A)	(¢/lb)
Flax	809	5.5 1/	North Dakota South Dakota Minnesota	Northeast	6.1	10
Sunflowers 2/	3,719	16.0	North Dakota Minnesota South Dakota	North central Northeast	11.4	8
Safflower	NA 3/	73.3	California	North central Northeast	7.0 4/	10
Rapeseed	NA	.05	Idaho	---	9.0 5/	12
Mustard	NA	4.4	North Dakota	North central	7.0 6/	9 7/

1/ 1977 plantings, last year available.
2/ Oil varieties only.
3/ Not available.
4/ Average yield in Montana (1980).
5/ Average yield in Canada.
6/ Yields are for only one year (1979) in North Dakota.
7/ Price is for yellow mustard seed. Brown and Oriental sell for about 7¢ per pound.

Source: USDA, Agricultural Statistics, (Washington, D.C.: United States Government Printing Office, various years); North Dakota Crop and Livestock Reporting Service, North Dakota Agricultural Statistics, North Dakota Department of Agriculture and USDA, ESCS, various years; Montana Crop and Livestock Reporting Service, Montana Agricultural Statistics, Montana Department of Agriculture and USDA, ESCS, various issues.

1. Flax

Production of flax, primarily for linseed oil, has declined in Montana and nationwide in the past several years. Demand for linseed oil has decreased with the increased popularity of latex-based paints. Flax meal, which is used as a livestock feed, accounts for 15 to 20 percent of the total value of the crop, rivaling soybean meal in price.

Current acreage planted to flax is unknown in Montana because statistics have not been published since the 1977 crop year, when approximately 5,500 acres were planted to flax, a decline of nearly 20,000 acres since 1970. Flax's record high in Montana was 606,000 acres in 1930.

Flax is grown largely on dryland where yields vary from 8 to 12 bushels per acre in a normal year and average farming conditions. Yield fluctuations result from such agronomic conditions as precipitation, soil moisture, average daily temperatures, insect infestations, and many other factors. The average U.S. yield for the past 10 years is 10.9 bushels per acre, somewhat higher than Montana yields.

From 70 to 90 percent of Montana's flax is grown in the Northeastern crop reporting district (Figure II-1). The North-central and Southeastern crop reporting districts also produce some flax.

Flax is an important crop in North Dakota, South Dakota, and Minnesota. Texas, like Montana, has some flax acreage. Total U.S. acreage has ranged from 700,000 to 1,500,000 acres in recent years, with 809,000 acres in 1980.

2. Sunflowers

Sunflower plantings for oil have increased dramatically in recent years. This increase came after plant breeding doubled the oil content of the seeds from 20 to 40 percent. Other breakthroughs led to increased seed yields per acre. Subsequently, plantings in the U.S. increased from 77,000 acres in 1970 to more than 5 million acres in 1979. Plantings in 1980 dropped to approximately 3.7 million acres.

Figure II-1. Montana Crop Reporting Districts

Oilseed sunflowers yield two valuable products, oil and meal. Sunflower oil is edible, has a high smoke point, and requires less refining than soybean oil. While a sizable domestic market has developed for sunflower oil in food products high in polyunsaturates, most U.S. sunflower oil is exported to Western Europe. Sunflower meal makes up nearly 25 percent of the total value of the sunflower crop. The meal is a livestock feed with a protein content of approximately 28 percent (compared to soybean meal's protein of 44 percent).

Data on sunflower production in Montana are insufficient to determine trends. But the approximately 16,000 acres planted in Montana in 1980 dropped from nearly 30,000 acres in 1979. Most of the plantings were in the North-central and Northeastern crop reporting districts (Figure II-1), particularly in Chouteau, Phillips, and Garfield counties.

The most important sunflower-producing states are North Dakota, South Dakota, Minnesota, and Texas. In 1980, North Dakota's nearly 2.3 million acres were more than 60 percent of total U.S. plantings. South Dakota had 524,000 acres; Minnesota, 860,000 acres; Texas High Plains, 524,000 acres.

Yields per acre in Montana were 1,020 pounds in 1979 but only 450 pounds in dry 1980. Nationwide, yields have varied between 1,000 to 1,300 pounds per acre (31.25 to 40.63 bushels) in recent years, except for the slightly below 1,000 pound-per-acre average in 1980.

Prices currently received by farmers in Montana are approximately $8.00 per hundredweight. Sunflower seed prices have fallen by about 20 percent since October 1981.

3. Safflower

Because of its nonyellowing properties, safflower oil was produced primarily for use in white paints until recently when it entered the edible oil market. Safflower production has increased dramatically since then. Much of the current domestic production is exported.

Recent data on safflower production are not available nationwide but California has been the principal safflower state, producing 90

percent of the U.S. crop in 1977. Other states reporting some safflower acreage include North Dakota, Montana, Nebraska, Colorado, Idaho, Utah, Washington, Texas, Arizona and Kansas.

Montana's safflowers are produced primarily in the North-central and Northeastern crop reporting districts (Figure II-1), with minor plantings in the Central and Southeastern crop reporting districts.

Safflower yields in Montana vary from 700 to 900 pounds per acre, well below California yields of 1,600 to 2,400 pounds per acre.

Safflower seed prices at the farm level are currently $200 per ton in Montana. Long term contracts for the 1983 crop are approximately $180 per ton.

4. Rapeseed (Brassica napus and B. campestris)

Rapeseed oil production ranked third worldwide among edible vegetable oil crops in 1980 behind soybean and sunflower. Canada is the largest producer of rapeseed in the world, with large quantities produced in the prairie provinces of Saskatchewan, Alberta, and Manitoba. Very little rapeseed is grown in the U.S.

In Canada rapeseed yields on summerfallow range from 900 to 1,100 pounds per acre. Rapeseed is also grown on stubble in Canada with yields of 70 to 80 percent of those on summerfallow.

Rapeseed oil is used primarily as a cooking and salad oil especially in Western Europe. Rapeseed meal is a high quality meal for feeding livestock because of a low glucosinolate content.

The average wholesale price for rapeseed oil in 1980 was approximately 47 cents per pound. Historical prices for the oilseed are not published although current prices in the Northwest are approximately 12¢ per pound.

In Canada, rapeseed was selling for approximately $250 (U.S. dollars) per metric ton at the farm gate in early summer 1982. Canadian rapeseed, known as Canola, is characterized by a low erucic acid and low glucosinolate content. Erucic acid is undesirable nutritionally in rapeseed oil, and rapeseed meal containing glucosinolate causes thyroid problems in animals that ingest it.

5. Mustard

Three types of mustard are grown and traded internationally: Yellow (Brassica hirta and Sinapis alba), Oriental (yellow-seeded B. juncea), and Brown (brown-seeded B. juncea) mustards. The Brown and Oriental types have seed size, growth habit, and agronomic performance similar to the two varieties of rapeseed (B. napus and B. campestris).

Mustard seed is used in salad dressings, pickles, and as a meat extender in prepared meat products, but it is used primarily for prepared or powdered mustard for table use. Oriental and brown mustards are used to make hot mustard, much of which is exported.

National data on plantings, yields, and locations are unavailable. Data are available on plantings of mustard in Montana during 1980 when 4,381 acres were reported to county ASCS offices. Most of this (3,380 acres) was located in the North-central crop reporting district (Figure II-1). Important counties are Glacier and Hill.

No data are available on per acre yields in Montana, but North Dakota in 1979 had approximately 45,500 acres that averaged 700 pounds of seed per acre.

Current Montana prices for yellow mustard seed are approximately 9¢ per pound. Brown and Oriental mustards sell at a discount to yellow, and are currently about 6¢ per pound. Prices received by farmers in Canada are somewhat higher because of government programs involving agricultural production.

B. Montana Agricultural Experiment Station Trials

Experimental trials have been conducted at the Eastern Agricultural Research Center (near Sidney) on oilseed crops the past several years. Flax, sunflowers, safflower, rapeseed, mustard, crambe and several other crops were tested under dryland and irrigated conditions to obtain information regarding yield, maturity, disease resistance, oil content, oil quality, and general adaptation. Using data from the experimental trials, this section presents an analysis of oil yields per acre for the crops tested. Only results from dryland experiments are presented.

Montana State University's Cooperative Extension Service also conducted yield tests on oilseed crops in a two-year study (1977 and 1978) at various locations in the Golden Triangle. Those results also are discussed, especially when they differ significantly from results at the Eastern Agricultural Research Center. Unfortunately, the results from the experiments in the Golden Triangle are unpublished. Preliminary reports lacked information on rainfall, fertilization, and other agronomic conditions crucial to interpreting the results.

Caution should be exercised in projecting the results from the experimental plots to farms because experimental plots get far more attention than crops on most farms do, so yields from the experimental plots usually are higher. Oil contents are also typically higher, probably due to the higher levels of fertilization.

Oil yields are presented in most cases assuming commercial extraction methods involving both pressing and solvent extraction when necessary. The much studied practice of on-the-farm press extraction is not considered due to the high cost of this activity in comparison with charges for commercial oilseed processing. For this analysis, the percentages of total oil recovered are based on estimates in Feed Manufacturing Technology (Pfost, ed., 1976).

1. Flax

Flax varieties have been tested for many years at the agricultural experiment station at Sidney. Although yield differences among flax varieties tend to be small, significant differences exist in maturity, disease resistance, oil content, and oil quality, so only four varieties were recommended for production in Montana: Linolt, Culbert, Wishek, and Dufferin. Estimates made on oil yields per acre are based, when possible, on those recommended varieties.

Results were published on only three of the recommended varieties from 1981 trials. The results are presented in Table II-2 along with computed oil yields per acre based upon solvent extraction technology. Critical experimental trial factors were:

Table II-2. Flax oil yields per acre based on agronomic data obtained from Montana dryland flax variety yield trials, 1981

Variety	Average oil content 1/	Average weight per bushel	Average plot yields 2/	Calculated oil yields per acre Solvent extraction 3/	
	(%)	(lbs)	(lbs/A)	(lbs)	(gallons) 4/
Linott	45.1	53.3	884.8	395.1	51.3
Dufferin	46.2	53.0	821.5	375.7	48.8
Culbert	45.4	53.2	808.6	363.4	47.2

1/ Oil content reported on a dry weight basis.
2/ A total of three tests plots, 80 square feet in area were analyzed for each variety.
3/ Oil yield computed assuming that 1 percent of the total oil content remains in the meal.
4/ One gallon of linseed oil weighs 7.7 pounds.

Source: Oil contents, per bushel weights and yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State University, EARC mimeograph research report 3, 1982; calculated oil yields are DPRA estimates.

- Previous crop, summer fallow
- Fertilizer (34-0-0) applied at 100 pounds per acre
- Seeding rate, 40 pounds per acre
- April 1-July 31 precipitation was 7.39 inches
- Plots were 80 square feet--4 rows, 20 feet long, 1 foot apart.

Results show little variation in yields among varieties. Average seed oil contents of the three varieties were nearly the same, from 45.1 to 46.2 percent. Oil yields per acre ranged from 47.2 to 51.3 gallons.

Extrapolations from one-year experimental trials may be misleading. The 1981 crop year may not have been typical because of variances in precipitation, average daily temperature, soil moisture, and many other factors, so Table II-3 gives yields from experiments from 1973 through 1981 for all varieties tested. Unfortunately, oil contents are not known; they are estimated by DPRA as 44 percent based upon 1981 experimental trial results. This percentage is somewhat higher than the 40 percent that typically occurs under average farming conditions.

From 1973 through 1981, the best yields were in 1979, 1,295 pounds of flaxseed per acre. Poorest yields were in 1977 when the test plots averaged only 610 pounds of flaxseed per acre. The average calculated yield for the 9 years was 993 pounds per acre, which gave oil yields per acre of 56.2 gallons assuming a flaxseed oil content of 44 percent.

Results from the 1977-78 tests in the Golden Triangle by the Cooperative Extension Service showed lower yields than those obtained at the Eastern Agricultural Research Center, and seed oil content was lower at Triangle locations, averaging just over 40 percent. Considering these results it is not surprising that most of the flax grown in Montana is in the Northeast crop reporting district, near Sidney.

2. Sunflowers

Sunflower varieties tested in 1981 for yield, seed oil content, disease resistance, etc., are presented in Table II-4. The results show wide differences in yields and seed oil contents among varieties. Yields, computed on a per acre basis from three test plots for each variety, ranged from 1,185 pounds to 2,080 pounds. Average oil contents

Table II-3. Flax oil yields per acre based on agronomic data obtained from dryland flax yield trials in Montana, 1973-1981

Experiment year	Mean yield	Estimated oil content 2/	Calculated oil yield per acre 3/	
	(lbs/A)	(%)	(lbs)	(gal) 4/
1973	1,280	44	557.6	72.4
1974	1/	-	---	---
1975	1/	-	---	---
1976	880	44	383.4	49.8
1977	610	44	265.7	34.5
1978	850	44	370.4	48.1
1979	1,295	44	563.6	73.2
1980	1,063	44	463.5	60.2
1981	971	44	422.7	54.9
AVERAGE	993	44	532.7	56.2

1/ No experiments were conducted on flax during 1974 and 1975.
2/ DPRA estimates of oil content on a dry weight basis.
3/ Solvent extraction assumed to recover 99 percent of total oil.
4/ One gallon is 7.7 pounds.

Source: Yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State University, EARC mimeograph research report 3, 1982; estimated oil content and calculated oil yields are DPRA estimates.

Table II-4. Sunflower oil yields per acre based on agronomic data obtained from dryland sunflower variety yield trials in Montana in 1981

Variety	Average oil content	Average weight per bushel	Average plot yields	Calculated oil yields per acre 2/	
	(%) 1/	(lbs)	(lbs/A)	(lbs)	(gal) 3/
PAG SF101	43.6	32.3	2,080	897.8	116.6
PAG SF102	43.0	32.0	1,921	817.8	106.2
Cargill 206	43.5	31.0	1,886	812.2	105.5
Cargill 205	43.1	32.5	1,829	780.4	101.4
Interstate 3100	45.2	29.7	1,786	799.2	103.8
Sigeo 472	40.6	30.2	1,770	711.4	92.4
Sigeo 448	44.9	30.3	1,713	761.4	98.9
Seedtec S-310	44.1	31.7	1,678	732.6	95.1
RBA 3101	33.9	30.2	1,659	556.8	72.3
Seedtec S-301A	44.5	32.0	1,652	727.8	94.5
RBA X5007	39.5	28.5	1,581	618.3	80.3
RBA X9407	40.7	29.3	1,447	583.0	75.7
RBA X5903	37.5	29.5	1,444	536.1	69.6
RBA X0505	35.7	29.7	1,426	504.0	65.5
Interstate 3107	44.1	31.7	1,410	615.6	79.9
Cargill 204	39.0	29.0	1,305	503.9	65.4
Peredovik	41.5	28.3	1,185	486.9	63.2

1/ Oil content reported on a dry weight basis.
2/ Extraction assumed to recover 99 percent of total oil.
3/ One gallon is 7.7 pounds.

Source: Oil contents, per bushel weights and yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State University, EARC mimeograph research report 3, 1982; calculated oil yields are DPRA estimates.

of the sunflower seeds ranged from a low of 33.9 to a high of 45.2 percent (measured on a dry weight basis). Weights per bushel of seed varied from 28.3 to 32.5 pounds.

The most productive oil variety was PAG SF101, which produced 116.6 gallons (897.8 pounds) per acre of oil. The least productive oil variety, Peredovik, yielded only 63.2 gallons per acre.

Critical experimental trial factors:

- Trial plots were 120 square feet, 3 row plots with rows 20 feet long, 2.0 feet apart
- Plant population, 17,424 plants per acre
- Seeding rates, 70 seeds per row, thinned to 20 plants per row
- Previous crop, summer fallow
- Fertilizer (34-0-0) applied at 100 pounds per acre
- April 1 - July 31 precipitation was 7.39 inches.

The 1981 results (Table II-4) showing substantial differences among sunflower varieties may not be representative of other years, so sunflower test-plot yields from 1976-81 experiments are given in Table II-5. Unfortunately, seed oil contents are not known but are estimated by DPRA to be 41 percent, based on data from 1981 experiments, experiments in the Golden Triangle in 1977 and 1978, and conversion factors from national statistics. Hence, oil yields are presented as a range. During the years when successful experiments were conducted, yields ranged from 590 pounds per acre in 1977 to 1,695 pounds per acre in 1980. The average yield for the six-year period was 1,233 pounds per acre.

Oil yields ranged from 31.1 gallons in 1977 when the yield was 590 pounds per acre to 89.3 gallons per acre in 1980 when the yield was 1,695 pounds. At the average yield of 1,233 pounds per acre, and oil content of 41 percent, oil yields total 65.0 gallons per acre. At this average, a one percent increase or decrease in seed oil content affects yields by 1.6 gallons (12.3 pounds) per acre.

Table II-5. Sunflower oil yields per acre based on agronomic data obtained from dryland sunflower yield trials in Montana, 1976-1981

Experiment year	Mean yield	Estimated oil content 1/	Calculated oil yield per acre 2/	
	(lbs/A)	(%)	(lbs)	(gal) 3/
1976	1,120	41	454.6	59.0
1977	590	41	239.5	31.1
1978	1,150	41	466.8	60.6
1979	1,210	41	491.1	63.8
1980	1,695	41	688.0	89.3
1981	1,634	41	663.2	86.1
AVERAGE	1,233	41	500.5	65.0

1/ Oil content estimated on a dry weight basis.
2/ Extraction assumed to recover 99 percent of total oil.
3/ One gallon is 7.7 pounds.

Source: Yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State Unviersity, EARC mimeograph research report 3, 1982; estimated oil content and calculated oil yields are DPRA estimates.

3. Safflower

Yield experiments were conducted on hundreds of varieties of safflower in 1981 at numerous sites. Yields varied widely at each site, indicating the importance of selecting the best variety for farm production. Recommended varieties for Montana in 1982 were Hartman, Rehbein, S-208, and Sidwill; 1981 test results for those varieties and calculated oil yields are in Table II-6.

Hartman had the highest seed oil content of the four varieties, averaging slightly more than 40 percent. Hartman also had the highest oil yields, exceeding 100 gallons at four of five experiment sites. Sidwill variety had seed yields nearly as high as Hartman but much lower seed oil content, averaging approximately 33.3 percent. Rehbein had seed oil contents slightly above Sidwill but low seed yields gave low per acre oil yields. S-208 generally had the lowest per-acre oil yields.

Critical experimental factors included:

- Previous crop, sugarbeets
- Fertilizer (34-0-0) at 100 pounds per acre
- Seeding rate, 20 pounds per acre (pure, live-seed basis)
- April 1 - July 31 precipitation was 7.39 inches
- Plots were 80 square feet or 4 rows 20 feet long, 1 foot apart.

Table II-7 gives the seed yields from 1973 through 1981 safflower experiments. Yields are averages of all plots for each year. Based upon results from 1981 and conversion factors from national statistics, the oil content was estimated to be 36 percent.

The 1973 seed yield of 2,000 pounds per acre was the highest. An average seed oil content of 36 percent would make oil yields exceed 90 gallons per acre of safflower. The lowest yield was only 735 pounds of seed per acre; the average 1,290 pounds per acre. The average would produce approximately 55.9 gallons of safflower oil with seed oil content of 36 percent. For each 1 percent increase (or decrease) in seed oil content, oil yields increase (decrease) 1.7 gallons (12.7 pounds) per acre.

Table II-6. Safflower oil yields per acre based on agronomic data obtained from Montana dryland safflower variety yield trials in 1981

Variety	Average oil content 1/	Average weight per bushel	Average plot yields	Calculated oil yields per acre 2/	
	(%)	(lbs)	(lbs/A)	(lbs)	(gal) 3/
Hartman	40.0	36.3	2,050	807.7	104.9
Sidwill	33.0	34.8	1,872	608.5	79.0
Rehbein	35.4	33.7	1,701	593.1	77.0
S-208	33.2	27.5	1,232	402.9	52.3
Sidwill	31.2	34.2	1,757	540.0	70.1
Hartman	39.8	35.0	1,754	687.6	89.3
Rehbein	34.2	32.2	1,409	474.6	61.6
S-208	32.6	27.5	1,256	403.3	52.4
Hartman	40.6	35.7	2,279	911.4	118.4
Sidwill	34.0	35.5	1,998	669.1	86.9
Rehbein	36.1	33.7	1,934	687.7	89.3
S-208	34.9	28.3	1,647	566.2	73.5
Sidwill	34.5	34.7	2,225	756.1	98.2
Hartman	41.0	35.8	2,198	887.7	115.3
Rehbein	34.4	33.2	1,818	616.0	80.0
Hartman	40.4	36.0	2,471	983.3	127.7
Sidwill	33.9	35.3	1,974	659.1	85.6
Rehbein	34.4	33.5	1,780	603.1	78.3

1/ Oil content reported on a dry weight basis.
2/ Extraction assumed to recover 98.5 percent of total oil.
3/ One gallon is 7.7 pounds.

Source: Oil contents, per bushel weights and yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State University, EARC mimeograph research report 3, 1982; calculated oil yields are DPRA estimates.

Table II-7. Safflower oil yields per acre based on agronomic data obtained from dryland safflower yield trials in Montana, 1973-1981

Experiment year	Mean yield	Estimated oil content 1/	Calculated oil yield per acre 2/	
	(lbs/A)	(%)	(lbs)	(gal) 3/
1973	2,000	36	709.2	92.1
1974	1,240	36	439.7	57.1
1975	1,300	36	461.0	59.9
1976	1,550	36	549.6	71.4
1977	1,060	36	375.9	48.8
1978	910	36	322.7	41.9
1979	1,365	36	484.0	62.9
1980	735	36	260.6	33.8
1981	1,454	36	515.6	70.0
AVERAGE	1,290	36	457.4	59.4

1/ Oil content estimated on a dry weight basis.
2/ Oil yields assume a solvent method of extraction recovering 98.5 percent of total oil.
3/ One gallon is 7.7 pounds.

Source: Yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State Unviersity, EARC mimeograph research report 3, 1982; estimated oil content and calculated oil yields are DPRA estimates.

Results from the Golden Triangle in 1977 and 1978 were not nearly so encouraging. Yields varied widely and were always lower than those presented above. Seed oil contents also were lower from all Golden Triangle experiments.

4. Rapeseed

Rapeseed yield trials were conducted with four varieties in 1981 at the Eastern Agricultural Research Center near Sidney, Montana, but only three plots on one site were used to test each variety. The 1981 results were considered crop failures so no data are presented.

Rapeseed yield trials conducted in previous years at the Eastern Agricultural Research Center, Sidney, Montana, were not encouraging either. From 1977 through 1980, yields averaged only 329 pounds per acre for Argentine rapeseed (*Brassica napus*) and only 458 pounds for Turnip rapeseed (*B. campestris*). But in Manitoba, Saskatchewan, and Alberta, Canada 1978 rapeseed yields averaged more than 2,500 pounds of seed per acre (Kondra, 1981). The same varieties were tested in each case. In similar tests with unnamed varieties in Idaho, Washington, and Oregon, test yields were approximately 2,000 pounds per acre in most areas tested (Peterson, et al., 1980).

No explanation for the low Montana yields was given. However, the Kondra study indicated that individual rapeseed varieties are not generally adaptable to a wide area because of different "agroclimatic zones." Kondra suggested identifying "agroclimatic zones" on the basis of rainfall, length of frost-free period, average daily temperature, soil type, and other pertinent factors. With that information the best performer for each area should be selected.

Tests conducted in the Golden Triangle in 1977 and 1978 were much more encouraging than the tests at Sidney. The likely reason for this is that this area has slightly cooler temperatures. According to researchers at the Eastern Agricultural Research Center, tests there were hampered by warm July temperatures when the rapeseed plant is in bloom and requires cool temperatures for the best results. It was thought that plantings in the cooler counties in the North-central district or plantings at higher elevations would produce more favorable results.

Table II-8 illustrates the results obtained at all locations in the Golden Triangle area in 1977 and 1978 by variety. These varieties, popular in Canada, produced average yields of 885 pounds per acre, somewhat below average yields in Canada. Oil yields per acre averaged 45.5 gallons.

5. Mustard

Only four varieties of mustard were tested in 1981 at the Eastern Agricultural Research Center (one Oriental, two Yellow, and one Brown). Yields, seed oil contents, and computed oil yields are presented in Table II-9. In the four trials, seed oil contents ranged from 24.5 to 34.3 percent and were inversely related to average weights per bushel of seed. Seed yields ranged from 839 to 1,087 pounds per acre. Calculated oil yields ranged from only 28.5 to 47.7 gallons per acre. Per acre yields of mustard oil are significantly lower than those of flax, sunflower, and safflower.

Important experimental factors included:

- The previous crop, sugarbeets
- Fertilizer (34-0-0) applied at 100 pounds per acre
- Seeding rates, 15 pounds per acre for Yellow mustard, 8 each for Oriental and Brown mustard
- Plots were 80 square feet
- April 1 - July 31 precipitation was 7.39 inches.

Table II-10 displays the results obtained from experiments at sites near the Golden Triangle in 1977 and 1978. These results indicate oil yield of nearly 32 gallons for Yellow, 25 gallons for Brown, and 47 gallons for Oriental.

6. Crambe

Crambe also was tested from 1973 through 1977 at the Eastern Agricultural Research Center near Sidney (Table II-11). Seed yields ranged from 330 to 1,610 pounds per acre, and averaged 1,086 pounds per acre. If the seed oil content were 30 percent and the oil extraction

Table II-8. Rapeseed oil yields per acre based on agronomic data obtained from dryland rapeseed trials in the Golden Triangle in Montana in 1977 and 1978 by variety

Variety	Mean yield	Estimated oil content 1/	Calculated oil yield per acre 2/	
	(lbs/A)	(percent)	(lbs)	(gal) 3/
Torch	867	40	343.3	44.6
Tower	942	40	373.0	48.4
C2yt-1821	795	40	314.8	40.1
Midas	861	40	341.0	44.3
Candle	982	40	388.9	50.5
WEIGHTED AVERAGE	885	40	350.5	45.5

1/ Oil contents not available for 1978 experiments. Oil contents from 1977 experiments were in excess of 40 percent.

2/ Assumes an extraction rate of 99 percent.

3/ One gallon is 7.7 pounds.

Source: Yields from G. D. Jackson, "Oilseed results - a two year study," Cooperative Extension Service, Montana State University, leaflet 244; estimated oil content and calculated oil yields are DPRA estimates.

Table II-9. Mustard oil yields per acre based on agronomic data from Montana dryland mustard variety yields trials, 1981

Mustard crop	Variety	Average oil content 1/	Average weight per bushel	Average plot yields	Calculated oil yield per acre 2/	
		(%)	(lbs)	(lbs/A)	(lbs)	(gal)
Oriental	Domo 23-25	34.3	50.3	1,087	367.2	47.7
Yellow	Sabre	24.9	54.2	939	230.3	29.9
Yellow	Yellow-2	24.5	54.8	908	219.1	28.5
Brown	Brown Comm.	29.6	52.7	834	243.2	31.6

1/ Oil content reported on dry weight basis.
2/ Oil yields based on extraction rate of 98.5 percent of total oil.

Source: Oil contents, per bushel weights and yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State University, EARC mimeograph research report 3, 1982; calculated oil yields are DPRA estimates.

Table II-10. Mustard oil yields per acre based on agronomic data obtained from dryland mustard yield trials in the Golden Triangle in Montana in 1977 and 1978

Variety	Mean yield	Estimated oil content 1/	Calculated oil yield per acre 2/	
	(lbs/A)	(percent)	(lbs)	(gal) 3/
Yellow	888	28	244.9	31.8
Brown	823	28	222.0	24.5
Oriental	1,233	30	364.3	47.3

1/ Oil contents not available for 1978 experiments. Oil contents are DPRA estimates based on 1977 results and previous results of experiments near Sidney, Montana.

2/ Assumes an oil extraction rate of 98.5 percent.

3/ One gallon is 7.7 pounds.

Source: Yields from G. D. Jackson, "Oilseed results - a two year study," Cooperative Extension Service, Montana State University, leaflet 244; estimated oil content and calculated oil yields are DPRA estimates.

Table II-11. Crambe oil yields per acre based on agronomic data obtained from dryland crambe yield trials in Montana, 1973-1977

Experiment year	Mean yield	Estimated oil content 1/	Calculated oil yield per acre 2/	
	(lbs/A)	(percent)	(lbs)	(gal) 3/
1973	1,610	30	475.8	61.8
1974	900	30	266.0	34.5
1975	1,230	30	363.5	47.2
1976	1,360	30	401.9	52.2
1977	330	30	97.5	12.7
AVERAGE	1,086	30	320.9	41.7

1/ Oil content is a DPRA estimate based on similar trials.

2/ Oil yields assume a solvent method of extraction recovering 98.5 percent of total oil.

3/ One gallon is 7.7 pounds.

Source: Yields from J. W. Bergman and R. L. Anderson, 1981 Summary of Data Obtained in Agronomic and Soils Experimental Trials-Eastern Agricultural Research Center, Sidney, Montana, Montana State Agricultural Experiment Station, Montana State University, EARC mimeograph research report 3, 1982; estimated oil content and calculated oil yields are DPRA estimates.

rate 98.5 percent, average oil yield would be approximately 41.7 gallons per acre; 30 percent seed oil content is similar to that in earlier tests of crambe on dryland acreage in Montana (White and Higgins, 1964).

III. NATIVE AND NATURALIZED MONTANA SPECIES WITH POTENTIAL AS OIL-BEARING PLANTS

Native and naturalized Montana species that might have potential as seed-oil or whole-plant-oil producers were identified. How they were identified and a list of species considered for sampling follow.

The identification procedure involved a two-phase approach. First an initial list of species with potential high oil levels was developed from an extensive literature search and contacts with knowledgeable professionals (e.g., taxonomists, agronomists, oilseed breeders, weed scientists, and ecologists). Published seed and plant analysis results and the field experience of professionals contacted served as major inputs to list development. Species from which currently cultivated varieties were derived were not included in the list as their potentials are already well documented through the breeding programs that produced the newer varieties. Second, species were eliminated from the initial list based on consideration of habitat constraints and preliminary agronomic evaluations. A prime consideration was whether a species would readily adapt to dryland agriculture in those areas of Montana presently cultivated. Plants whose form or stature would cause harvesting difficulties and those whose size would prevent adequate yields were eliminated. Species remaining after eliminations were considered for sampling.

The first of two following sections examines oilseed species; the second, whole-plant-oil species.

A. Oilseed Species

Oilseed species are of interest because their seeds contain oil. This section discusses the process used to identify species from Montana flora that may have such potential. Difficulties in estimating seed oil yields from information obtained from natural populations also are discussed.

1. Oilseed Species Inventory

Ideally, identification of native and naturalized species with potential as seed-oil producers would involve screening and testing a large number of native plants. We used a two-phased approach to develop the list of species eventually considered for testing. The initial list containing plants with high seed oil, developed from the literature search and contacts with knowledgeable professionals, was narrowed by consideration of habitat constraints and preliminary agronomic evaluations. Those species remaining were considered for sampling.

a. Comprehensive species list.

Our survey of the literature involved searching the Bibliography of Agriculture, Science Index, Seed Abstracts, Weed Abstracts, Economic Botany , Canadian Journal of Plant Science, Crop Science, and Agronomy Journal. We also contacted representatives at several state universities (e.g., Montana State University, South Dakota State University, Kansas State University, University of Wyoming, and Oregon State University) and the Saskatchewan Research Council in Saskatoon.

Two major information sources emerged from the search: the work conducted by USDA's Northern Regional Research Center in Peoria, Illinois (Barclay and Earle 1974; Jones and Earle 1966; Earle and Jones 1962) (hereafter referred to as the USDA work) and Dr. Robert Eslick's research at Montana State University on Cruciferae (Mustard family) with seed oils high in erucic acid (reported in Georing, Eslick, and Brelsford 1965). The USDA work provided a broad base of seed-analysis information with results for more than 2,000 species. The second study, while less comprehensive, examined several Cruciferae (Mustard family) from Montana. Other studies used included Coxworth (1965) and Coxworth, Bell, and Ashford (1969).

Using the results of these studies and floras from Montana and surrounding areas (Booth and Wright 1966; Great Plains Flora Association 1977 and n.d.; Van Bruggen 1976), we developed an initial list

(Table III-1) of potential seed oil producing plants by identifying species meeting these two criteria:

- Montana native or naturalized and examined in these studies
- Seed oil content of 30 percent or more. 1/

Exceptions were species related to currently cultivated oilseed plants (noted in Table III-1).

To broaden the range of species examined beyond those already reported in the literature, we identified genera whose members have reported seed oil contents of at least 30 percent, and we contacted knowledgeable professionals at Montana State University and at major universities in states surrounding Montana. For the former, we first reexamined available seed analysis data, and using Booth and Wright's Flora of Montana (1966) developed a list of species (included in Table II-2) with the following important characteristics:

- Native or naturalized Montana species
- In genera whose members have at least 30 percent seed oil content
- No seed analysis data available to us.

Species that met the first two criteria, but had available seed analysis data were eliminated if their oil contents were less than 30 percent. Those whose seed analysis data indicated at least 30 percent oil content were already included in Table III-1.

In the second activity used to broaden the range of species examined and listed in Table III-1, we contacted ecologists, taxonomists, plant breeders, soil scientists, and agronomists at Montana State University for suggestions of potential oilseed plants. That helped assure that we missed no obvious species that should be considered. Representative scientists from North Dakota State University, South Dakota State University, University of Montana,

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1/ That level was suggested by USDA's Northern Regional Research Center investigators as a rule of thumb for species that may have potential as seed-oil producers.

Table III-1. Native and naturalized Montana species identified through a literature search as potential seed oil producers: species with seed analysis data

Family	Species	Common name
Asclepiadaceae	Asclepias syriaca	Common Milkweed
Asteraceae	Artemisia absinthium	Wormwood, Common Sagewort
	A. campestris	Field Sagewort
	A. dracunculus	False-tarragon Sagewort
	A. frigida	Fringed Sagewort
	Bidens frondosa	Devils Beggartick
	Helianthus maximilianii	Maximilian Sunflower
	H. nuttallii 1/	Nuttall Sunflower
	H. petiolaris	Prairie Sunflower
	H. tuberosus 1/	Jerusalem Artichoke
	Solidago canadensis	Canada Goldenrod
	Xanthium strumarium	Cocklebur, Cow Cockle
Brassicaceae	Arabis drummondii	Drummond's Rockcress
	Brassica kaber 2/	Wild Mustard, Charlock
	B. nigra	Black Mustard
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax
	C. sativa	Falseflax
	Descurainia pinnata	Tansymustard
	D. sophia	Flixweed
	Isatis tinctoria	Dyer's Woad, Yellow Woad
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard
	S. loeselii	Loesel Tumble Mustard
	Thlaspi arvense	Field Pennycress, Fanweed
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed
	Polanisia trachysperma	Clammy-weed
Caprifoliaceae	Lonicera tatarica	Honeysuckle
Cucurbitaceae	Echinocystis lobata	Mock Cucumber
Ericaceae	Arctostaphylos uva-ursi	Kinnikinnick
Euphorbiaceae	Euphorbia marginata	Snow-on-the-Mountain
Hypericaceae	Hypericum perforatum	Common St. John's Wort
Lamiaceae	Galeopsis tetrahit	Brittlestem Hempnettle
	Monarda fistulosa	Horse Mint, Wild Bergamot
Linaceae	Linum perenne 3/	Wild Blue Flax
Loasaceae	Mentzelia decapetala	Tenpetal Blazingstar, Sand Lily
	M. dispersa	Scattered Stickleaf
	M. nuda	Plains Evening-Star
Onagraceae	Gaura parviflora	Small-Flowered Gaura
Papaveraceae	Argemone polyanthemos	Prickly Poppy
Rosaceae	Potentilla arguta	Tall (Glandular) Cinquefoil
	Prunus virginiana	Common Chokecherry
Solanaceae	Hyoscyamus niger	Black Henbane

1/ Included though oil content was less than 30 percent for its relationship to the cultivated sunflower.
2/ Included though oil content is less than 30 percent for its relationship to rapeseed and cultivated mustards.
3/ Included though oil content is less than 30 percent for its relationship to cultivated flax.

Sources: A. S. Barclay and F. R. Earle, "Chemical Analysis of Seeds III: Oil and Protein Content of 1,253 Species," Economic Botany 28(1974):178-236; E. C. M. Coxworth, "Oil and Protein Content and Comparison of the Seeds of Some Plants of the Canadian Prairies," Journal of the American Oil Chemists Society 42(1965):891-844; E. C. M. Coxworth, J. M. Bell and R. Ashford, "Preliminary Evaluation of Russian Thistle, Kochia and Green Atriplex as Potential High Protein Seed Crops for Semiarid Areas," Canadian Journal of Plant Science 49(1969):427-434; Q. Jones and F. R. Earle, "Analysis of Seed Samples from 113 Plant Families," Economic Botany 16(1962):221-250; K. J. Georing, R. Eslick, and D. L. Brelsford, "A Search for High Erucic Acid Containing Oils in Cruciferae," Economic Botany 19(1965):251-256; Q. Jones and F. R. Earle, "Chemical Analysis of Seeds II: Oil and Protein Content of 759 Species," Economic Botany 20(1966):127-155.

Table III-2. Native and naturalized Montana species identified as potential seed oil producers: species without seed analysis data or suggested by knowlegeable professionals

Family	Species	Common name
Asclepiadaceae	Asclepias speciosa	Showy Milkweed
Asteraceae	Achillea millefolium	Yarrow
	Agoseris glauca	Pale Agoseris
	Anthemis cotula	Dog-fennel
	Arctium lappa	Great Burdock
	Artemisia annua	Sweet Sagewort
	A. biennis	Biennial Sagewort
	A. cana	Silver Sagebrush
	A. longifolia	Longleaf Sagebrush
	A. ludoviciana	Cudweed Sagewort
	A. pedatifida	Birdfoot Sagebrush
	A. tridentata	Big Sagebrush
	A. tripartita	Threetip Sagebrush
	Aster foliaceous	Leafy Aster
	A. laevis	Smooth Aster
	A. pansus	Tufted White Prairie Aster
	Echinacea pallida	Pale Purple Coneflower
	Kuhnia eupatorioides	False Boneset
	Liatris ligulistylis	Blazingstar
	L. punctata	Dotted Blazingstar
	Senecio canus	Wooly Groundsel
	Tetradymia canescens	Gray Horsebrush
Brassicaceae	Berteroa incana	Berteroa
	Conringia orientalis	Hare's-ear Mustard
	Lepidium campestre	Field Pepperweed
	L. densiflorum	Prairie Pepperweed
	Lesquerella alpina	Alkaline Bladderpod
	L. curvipes	Bladderpod
	L. ludoviciana	Silvery Bladderpod
	Schoenocrambe linifolia	Flaxleaved Plains Mustard
	Sisymbrium officinale	Hedge Mustard
	Stanleya pinnata	Bushy Stanleya
	S. viridiflora	Perennial Stanleya
	Thelypodium integrifolium	Entireleaved Thelypody
	T. laciniatum	Thickleaved Thelypody
Capparidaceae	Cleome lutea	Yellow Bee Plant
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress
Euphorbiaceae	Euphorbia cyparissias	Cypress Spurge
	E. esula	Leafy Spurge
	E. glyptosperma	Ridge-seeded Spurge
	E. helioscopia	Summer (Sun) Spurge
	E. hexagona	Sixangle Spurge
	E. missurica	Missouri Spurge
	E. robusta	Robust Spurge
	E. serpyllifolia	Thyme-leaved Spurge
	E. serpens	Serpent Spurge
	E. spathulata	Spatula-leaved Spurge
Linaceae	Linum rigidum	Yellow Flax
Loasaceae	Mentzelia albicaulis	White-stemmed Blazingstar
	M. laevicaulis	Fivepetal Blazingstar
Ranunculaceae	Thalictrum venulosum	Veiny Meadowrue

Continued...

Table III-2. (Continued)

Family	Species	Common name
Scrophulariaceae	Linaria dalmatica	Dalmation Toadflax
	L. vulgaris	Butter and Eggs
	Verbascum thapsus	Common Mullein

Sources: A. S. Barclay and F. R. Earle, "Chemical Analysis of Seeds III: Oil and Protein Content of 1,253 Species," Economic Botany 28(1974):178-236; E. C. M. Coxworth, "Oil and Protein Content and Comparison of the Seeds of Some Plants of the Canadian Prairies," Journal of the American Oil Chemists Society 42(1965):891-844; E. C. M. Coxworth, J. M. Bell and R. Ashford, "Preliminary Evaluation of Russian Thistle, Kochia and Green Atriplex as Potential High Protein Seed Crops for Semiarid Areas," Canadian Journal of Plant Science 49(1969):427-434; Q. Jones and F. R. Earle, "Analysis of Seed Samples from 113 Plant Families," Economic Botany 16(1962):221-250; K. J. Georing, R. Eslick, and D. L. Brelsford, "A Search for High Erucic Acid Containing Oils in Cruciferae," Economic Botany 19(1965):251-256; Q. Jones and F. R. Earle, "Chemical Analysis of Seeds II: Oil and Protein Content of 759 Species," Economic Botany 20(1966):127-155; and interviews with knowledgeable professionals.

University of Wyoming, and the University of Idaho also were contacted. Additional species suggested and included in Table III-2 were:

- Agoseris glauca (Pale Agoseris)
- Arctium lappa (Great Burdock)
- Asclepias speciosa (Showy Milkweed)
- Aster foliaceous (Leafy Aster)
- Aster laevis (Smooth Aster)
- Aster pansus (Tufted White Prairie Aster)
- Berteroa incana (Berteroa)
- Conringia orientalis (Hare's-ear Mustard)
- Echinacea pallida (Pale Purple Coneflower)
- Kochia scoparia (Kochia, Summer Cypress)
- Kuhnia eupatorioides (False Boneset)
- Lepidium campestre (Field Pepperweed)
- Lepidium densiflorum (Prairie Pepperweed)
- Liatris ligulistylis (Blazingstar)
- Liatris punctata (Dotted Blazingstar)
- Senecio canus (Wooly Groundsel)
- Stanleya pinnata (Bushy Stanleya)
- Stanleya viridiflora (Perennial Stanleya)
- Tetradymia canescens (Gray Horsebrush)
- Thelypodium integrifolium (Entireleaved Thelypody)
- Thelypodium laciniatum (Thickleaved Thelypody)
- Verbascum thapsus (Common Mullein)

b. Species retained following preliminary screening.

The purpose of eliminating species was to remove, before field sampling began, those that likely would have difficulty adapting to dryland agriculture in Montana 2/. Plant breeders at Kansas State

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2/ In making up the two initial lists, we usually did not include species found only in mountainous regions or appeared from floras to have high water requirements.

University and agricultural experts at Montana State University were consulted on species characteristics that might be considered highly undesirable for developing a cultivable crop. Their suggestions and available information from the floras of Montana and surrounding areas led to our eliminating species as discussed below.

Perennials may concern growers because they would have to wait at least two years for a return on a perennial and a perennial oilseed crop would have to compete with established oilseeds crops, which are all annuals. The delay in return, however, would be offset by reduced tillage costs and topsoil loss. If the seed and oil production of a perennial were high enough and began in the second year, it could provide a better long-run return than an annual crop.

Perennials might have further advantages over annuals during droughts, if the perennial were established before the drought began.

Given those considerations, plants were not eliminated because they were perennial; instead, limitations based on yield and handling factors were considered. In tables other than III-1 and III-2, annuals and perennials are separated because perennials would be subjected to a different set of criteria before being considered viable crop plants.

For additional information on size, form, and habitat constraints (i.e., temperature and moisture requirements) for species in Tables III-1 and III-2, we visited the herbarium at Montana State University and ecologists knowledgeable on field information for those species. Additional floras utilized included Hitchcock and Cronquist (1973), Welsh (1973), Weber (1972), and USDA (1971).

Tables III-3 (perennials) and III-4 (annuals) list species we eliminated, with explanations of why each was not considered further.

Tables III-5 and III-6 list the set of native and naturalized Montana species likely having potential as seed-oil producers. Of the annuals and perennials presented in the two tables, annuals likely have the greater near-term potential as their shorter generation time will facilitate breeding programs. With annuals, plant breeders need not select for year-of-first-seed-set as with perennials. Time of first seed set is not always known for a given perennial species and, in some species, plants have to be three or more years old before they

Table III-3. Native and naturalized Montana perennials eliminated from further consideration

Family	Species	Common name	Reason eliminated
Asteraceae	Agoseris glauca	Pale Agoseris	Would likely need irrigation if cultivated
	Arctium lappa	Great Burdock	Would likely need irrigation if cultivated; secondary sources indicate oil levels are likely well below 30 percent
	Artemisia absinthium	Wormwood, Common Sagewort	Would likely need irrigation if cultivated
	A. biennis 1/	Biennial Sagewort	Moisture requirements may call for irrigation in most places in Montana if cultivated
	A. cana	Silver Sagebrush	Shrub; may be difficult to harvest; usually does not flower until third or fourth year
	A. dracunculus	False-tarragon Sagewort	Would likely need cultivation if cultivated
	A. longifolia	Longleaf Sagebrush	Restricted to acid shale soils
	A. pedatifida	Birdfoot Sagebrush	Decumbant shrub, probably difficult to harvest
	A. tridentata	Big Sagebrush	Shrub, probably difficult to harvest; usually does not flower until third or fourth year
	A. tripartita	Threetip Sagebrush	Same as Artemisia tridentata
	Aster foliaceous	Leafy Aster	Would likely need irrigation if cultivated
	A. laevis	Smooth Aster	Would likely need irrigation if cultivated
	A. pansus	Tufted White Prairie Aster	Would likely need irrigation if cultivated
	Helianthus nuttallii	Nuttall Sunflower	Uncommon; moisture requirements may call for irrigation
	H. tuberosus	Jerusalem Artichoke	Rare; central and eastern U.S. species; moisture requirements may call for irrigation
	Liatris ligulistylis	Blazingstar	Rare in Montana; would likely need irrigation in most parts of Montana if cultivated
	Senecio canus	Wooly Groundsel	Would likely need irrigation if cultivated; short, only 1-4 dm tall
	Solidago canadensis	Canada Goldenrod	Western Montana; would likely need irrigation
	Tetradymia canescens	Gray Horsebrush	Would likely need irrigation if cultivated; short, only 2-6 dm tall
Brassicaceae	Lesquerella curvipes	Bladderpod	Very rare in Montana
	Schoenocrambe linifolia	Flaxleaved Plains Mustard	Rare; principally Western Montana and west of Cascade Mountains in Washington; would likely need irrigation if cultivated
Caprifoliaceae	Lonicera tatarica	Honeysuckle	Ornamental; would likely need irrigation if cultivated
Ericaceae	Arctostaphylos uva-ursi	Kinnikinnick	Prostrate to decumbent; may need irrigation
Euphorbiaceae	Euphorbia cyparissias	Cypress Spurge	Rare in Montana; likely higher water requirements because it is a garden escape growing along roadsides; plants are small, 10-30 cm tall.
	E. robusta	Robust Spurge	Short; likely does not produce enough biomass to be worth cultivating
Hypericaceae	Hypericum perforatum	Common St. John's Wort	Mesic foothills; likely need irrigation if cultivated
Lamiaceae	Monarda fistulosa	Bee Balm, Horse Mint, Wild Bergamot	Probably need irrigation if cultivated

Continued....

Table III-3. (Continued)

Family	Species	Common name	Reason eliminated
Ranunculaceae	Thalictrum venulosum	Veiny Meadowrue	Mesic forest species; may need irrigation if cultivated
Rosaceae	Potentilla arguta	Tall (Glandular) Cinquefoil	Mesic foothills; grasslands and prairie; likely need irrigation if cultivated
	Prunus virginiana	Common Chokecherry	Mesic shrub; likely need irrigation if cultivated
Scrophulariaceae	Linaria dalmatica	Dalmation Toadflax	Likely need irrigation
	L. vulgaris	Butter and Eggs	Likely need irrigation
	Verbascum thapsus 2/	Common Mullein	Would likely need irrigation if cultivated

1/ Biennial.

2/ Biennial to perennial.

Source: Development Planning and Research Associates, Inc.

Table III-4. Native and naturalized Montana annuals eliminated from consideration

Family	Species	Common name	Reason eliminated
Asteraceae	Anthemis cotula	Dog-Fennel	Found primarily in extreme NW Montana; temperature and perhaps moisture requirements may restrict its range
	Artemisia annua	Sweet Sagewort	Rare; habitat requirements restrictive, no known sites for collection in Montana (Harvey, 1981)
	Bidens frondosa	Devils Beggartick	Great Plains species; Eastern Montana extreme edge of range; habitat requirements too mesic and warm for most of Montana
Brassicaceae	Arabis drummondii	Drummond's Rockcress	Higher elevations; open woods; higher moisture requirements, likely need irrigation if cultivated
	Berteroa incana	Berteroa	Would likely need irrigation if cultivated
	Brassica nigra	Black Mustard	Uncommon in Montana (if found will often be along irrigated fields); may need irrigation in most parts of Montana
	Camelina sativa	Falseflax	Rare; irrigated fields and moist areas; likely need irrigation under cultivation
	Conringia orientalis	Hare's-ear Mustard	Would likely need irrigation if cultivated
	Lepidium campestre	Field Pepperweed	Would likely need irrigation if cultivated; short, only 2-4 dm tall
	L. densiflorum	Prairie Pepperweed	Would likely need irrigation if cultivated; short, only 2-4 dm tall.
	Sisymbrium officinale	Hedge Mustard	Rare; found only in extreme Northwest corner of Montana (range principally eastern U.S. and W. of Cascades), requires more moisture and warmer temperatures than found in Montana's dryland farming areas
Capparidaceae	Cleome lutea	Yellow Bee Plant	Very rare in Montana; range appears to be south of state
	Polanisia trachysperma	Clammy-weed	Rare; may need irrigation in many parts of Montana if cultivated
Cucurbitaceae	Echinocystis lobata	Mock Cucumber	May need irrigation in many places of Montana if cultivated
Euphorbiaceae	Euphorbia glyptosperma	Ridge-seeded Spurge	Grows too close to ground (semi-prostrate to decumbent), difficult to harvest
	E. helioscopia	Summer (Sun) Spurge	Rare; found only in extreme northwest corner of Montana; requires more moisture and warmer temperatures than found in Montana's dryland farming areas
	E. hexagona	Sixangle Spurge	Very rare in Montana; primarily found in southern half of South Dakota in sandy areas
	E. missurica	Missouri Spurge	From herbarium samples plant appears to be small and decumbent; fruits are small and few in number
	E. serpyllifolia	Thyme-leaved Spurge	Grows too close to ground (semi-prostrate to decumbent), difficult to harvest
	E. serpens	Serpent Spurge	Grows too close to ground (semi-prostrate to decumbent), difficult to harvest; also rare in Montana
Lamiaceae	Galeopsis tetrahit	Brittlestem Hempnettle	May need irrigation in many places in Montana if cultivated
Linaceae	Linum rigidum	Yellow Flax	Plant too small (stems-1-1.5 dm) would likely not produce enough biomass and seeds to be profitable
Loasaceae	Mentzelia albicaulis	White-stemmed Blazingstar	From herbarium samples, plant appears small; flowers are small and sparce; collections are all from higher elevations; rare in Montana
Solanaceae	Hyoscyamus niger	Black Henbane	Would likely need irrigation if cultivated

Source: Development Planning and Research Associates, Inc.

Table III-5. Native and naturalized Montana perennials retained as potential oilseed plants after preliminary habitat and agronomic examination

Family	Species	Common name	Habitat 2/
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	Stream banks, moist meadows
	A. syriaca	Common Milkweed	Fields and waste places
Asteraceae	Achillea millefolium	Yarrow	Plains and mountain valleys
	Artemisia campestris 1/	Field Sagewort	Rocky or sandy places
	A. frigida	Fringed Sagewort	Prairies and plains
	A. ludoviciana	Cudweed Sagewort	Grasslands and dry lawns
	Echinacea pallida	Pale Purple Coneflower	No habitat given
	Helianthus maximilianii	Maximilian Sunflower	Prairies and plains
	Kuhnia eupatorioides	False Boneset	Dry hillsides and prairies
	Liatris punctata	Dotted Blazingstar	Grasslands
Brassicaceae	Lesquerella alpina	Alkaline Bladderpod	Mountain slopes and plains
	L. ludoviciana	Silvery Bladderpod	Rocky slopes of hills and plains
	Stanleya pinnata	Bushy Stanleya	Dry grasslands
	S. viridiflora	Perennial Stanleya	Dry hills
	Thelypodium integrifolium 1/	Entireleaved Thelypody	Grasslands
	T. laciniatum 1/	Thickleaved Thelypody	Grasslands
Euphorbiaceae	Euphorbia esula	Leafy Spurge	Field and range weed
Linaceae	Linum perenne	Wild Blue Flax	Grasslands
Loasaceae	Mentzelia decapetala 1/	Tenpetal Blazingstar, Sand Lily	Canyons and roadcuts in gravel
	M. dispersa	Scattered Stickleaf	Dry sandy or gravelly soils
	M. laevicaulis	Fivepetal Blazingstar	Gravelly or sandy soil
	M. nuda 1/	Plains Evening-Star	Gravelly or sandy soil

1/ Biennial to perennial

2/ W. E. Booth and J. C. Wright, Flora of Montana, Part II, (Bozeman, Montana. Montana State University 1966); T. Van Bruggen, The Vascular Plants of South Dakota, (Ames, Iowa: Iowa State University Press, 1976).

Source: Development Planning and Research Associates, Inc.

Table III-6. Native and naturalized Montana annuals retained as potential oilseed plants after preliminary habitat and agronomic examination

Family	Species	Common name	Habitat 2/
Asteraceae	Helianthus petiolaris	Prairie Sunflower	Sandy oil and waste places
	Xanthium strumarium	Cocklebur, Cow Cockle	Fields and waste places
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	Fields and waste places
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	Disturbed areas
	Descurainia pinnata	Tansymustard	Sandy soil
	D. sophia	Flixweed	Waste areas
	Isatis tinctoria 1/	Dyer's Woad, Yellow Woad	Roadsides
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	Waste places
	S. loeselii	Loesel Tumble Mustard	Waste places and oil fields
	Thlaspi arvense	Field Pennycress, Fanweed	Fields and roadsides
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	Plains and roadsides
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	Wastelands
Euphorbiaceae	Euphorbia marginata	Snow-on-the-Mountain	Dry plains and valleys
	E. spathulata	Spatula-leaved Spurge	Sand spots or openings in grasslands
Onagraceae	Gaura parviflora 1/	Small-flowered Gaura	Gravelly or sandy soil
Papaveraceae	Argemone polyanthemos	Prickly Poppy	Plains

1/ Annual or biennial

2/ W. E. Booth and J. C. Wright, Flora of Montana, Part II, (Bozeman, Montana. Montana State University 1966); T. Van Bruggen, The Vascular Plants of South Dakota, (Ames, Iowa: Iowa State University Press, 1976).

Source: Development Planning and Research Associates, Inc.

reproduce. Another phenomenon observed in natural populations of perennials is that not all plants in the same population begin reproduction at the same age. Thus, for some perennial species, selection through plant breeding may be needed to assure that all plants in the same field begin reproducing at the same age.

Another factor boosting the near term potential of annual oilseed crops over perennial ones is that Montana farmers often use crop rotation to help maintain soil fertility and reduce insect problems. Fitting a perennial into such a cycle may be difficult. In the normal rotation sequence it might be time to switch to another crop before a perennial oilseed crop would show long term returns in excess of what could be obtained from an annual oilseed crop.

Promising perennials might be bred into annuals but long plant generation times in the early stages of such programs would slow the process and according to plant breeders at Kansas State University, life length is one of the hardest characteristics to alter genetically. Consequently, we focused most of our sampling on the annuals. Only two perennials were examined further, _Euphorbia esula_ (Leafy Spurge) and _Mentzelia decapetala_ (Tenpetal Blazingstar, Sand Lily). Leafy spurge was investigated because there is such an interest in this noxious weed species and we could find no seed analysis data for it. The Tenpetal Blazingstar was sampled because of the high oil levels found in the _Mentzelia_ genus (37-47 percent). It was chosen over the other Montana species of _Mentzelia_ because it is fairly common and could be sampled easily.

Although most perennials were given a lower priority by this study, they should by no means be eliminated as potential seed oil producers. Therefore, should DNRC decide at some later time to examine perennial oilseed plants, those species listed in Table III-5 are recommended for further research.

2. Yield Estimates

Because the only accurate way to obtain estimated yields for native and naturalized species is to grow them under controlled monocultural situations, we did not estimate their yields. Plant spacing in nature often reflects seed dispersal patterns, site requirements (e.g.,

temperature, moisture, vegetative cover) needed for seedling survival, chemical interactions between neighboring plants (allelopathy), and competition. Consequently, it is difficult to estimate what the optimum spacing for these species should be. Individual plant yields at cultivated spacings would be hard to predict because plants in a natural situation are subjected to both inter- and intra-specific competition, both of which can affect yields. Environmental factors, including edaphic (soil) ones, also confound such estimates. Without knowing the factors a plant has been exposed to, it would be impossible to make dependable yield estimates.

B. Whole-plant-oil Species

Whole-plant-oil species are of interest for the oil contained in the entire plant. Unlike oilseed plants where only the seeds are used, whole-plant-oil species are clipped at ground level and oil is extracted from the stem, leaves and reproductive structures. This section discusses how we identified, from Montana's flora, those with potential for such oil production. The difficulty encountered in estimating oil yields from information obtained from natural populations also is discussed.

1. Whole-plant-oil Species Inventory

As with oilseeds, the inventory of whole-plant-oil species contained two major phases. First, an initial list of potential species was developed on the basis of a literature search and consulting with taxonomists, agronomists, oilseed breeders, and weed scientists at Montana State University and at major universities in surrounding states. Second, species were eliminated by consideration habitat constraints and preliminary agronomic evaluations. Those remaining were considered for sampling.

a. Comprehensive species list

Probably one of the most extensive searches for species with potential for fuel or rubber production was conducted by a team of researchers from the USDA's Northern Regional Research Center in Peoria,

Illinois. Published papers from that group include: Bagby, Buchanan, and Otey (1982); Buchanan, Cull, Otey, and Russell, (1977 and 1978); Buchanan and Duke (n.d.); Buchanan, Otey, and Bagby (1980); Buchanan, Otey, and Hamerstrand (1980); Buchanan, Otey, Russell, and Cull (1978); Buchanan, Swanson, Weisleder, and Cull (1978); Swanson, Buchanan, and Otey (1979). A recent unpublished paper (Roth, Cull, Buchanan, and Bagby 1982) rated the 508 species examined by that team according to the species' ability to provide renewable energy (i.e., potential as hydrocarbon or oil-producing crops). Their rating considered the following factors: growth potential, ability to regrow after clipping, and oil, protein, and hydrocarbon concentration of plant extract. Roth, Cull, Buchanan, and Bagby (1982) concluded plants with ratings of 11 or less were worth considering further (those rated 8 or less of high interest; those rated 9 or 10 of medium interest).

We developed an initial list of potential oil-bearing Montana plants by isolating from the 508 rated species (Roth et al. 1982), those that met these criteria:

- Rated 11 or less, and
- Native or naturalized Montana species

They are ranked in Table III-7.

Other species with possible potential (Table III-8) were identified from other studies and from knowledgeable professionals as outlined below.

Native Plants, Inc. of Salt Lake City, Utah, is currently conducting a study, funded through the Biomass Group of the United States Department of Energy (managed by USDA), designed to screen Great Plains species for potential as whole-plant oil and hydrocarbon producing plants. Their report will not be available for several months. But one species that interests Native Plants, Inc. is <u>Asclepias speciosa</u> (Showy Milkweed). That company already has begun cultivation testing in Utah. Similar work is being performed at the Saskatchewan Research Council, in Saskatoon. Because <u>A. speciosa</u> also was suggested by several individuals at Montana State University and because it is one of the commoner milkweeds in Montana, we included it for further consideration (Table III-8).

Table III-7. Native and naturalized Montana species with possible potential as whole-plant-oil species as determined from USDA data 1/

Family	Species	Common name
	A. Species of High Interest 2/	
Anacardiaceae	Rhus glabra	Smooth Sumac
Caprifoliaceae	Sambucus canadensis	American Elderberry
	B. Species of Medium Interest 3/	
Apocynaceae	Apocynum androsaemifolium	Spreading Dogbane
Asclepiadaceae	Asclepias syriaca	Common Milkweed
	A. tuberosa	Butterfly-weed
	A. verticillata	Whorled Milkweed
Asteraceae	Ambrosia trifida	Tall Ragweed
	Solidago graminifolia	Grassleaf Goldenrod
	S. rigida	Stiff Goldenrod
	Sonchus arvensis	Field Sowthistle
Caprifoliaceae	Lonicera tatarica	Honeysuckle
	Symphoricarpos orbiculatus	Coralberry
Gramineae	Agropyron repens	Quack Grass
	C. Species of Possible Interest 4/	
Aceraceae	Acer negundo	Boxelder
	A. platanoides	Norway Maple
Apocynaceae	Apocynum cannabinum	Indian Hemp, Hemp Dogbane
Asteraceae	Achillea millefolium	Yarrow
	Carduus nutans	Musk Thistle
	Chrysothamnus nauseosus	Rubber Rabbitbrush
	Cirsium arvense	Canada Thistle
	Lactuca canadensis	Canada Lettuce
	Sonchus oleraceus	Common Sowthistle
Chenopodiaceae	Chenopodium album	Lambsquarter, White Goosefoot
Euphorbiaceae	Euphorbia esula	Leafy Spurge
Gramineae	Elymus canadensis	Canada Wildrye
Juglandaceae	Juglans nigra	Black Walnut
Lamiaceae	Leonurus cardiaca	Motherwort
	Lycopus americanus	(Cut-leaved) Water Horehound
	Mentha arvensis	Field Mint
	Monarda fistulosa	Horse Mint, Wild Bergamot
	Nepeta cataria	Catnip
Leguminosae	Amorpha canescens	Lead Plant
	Astragalus americanus	American Milk Vetch
	Gleditsia triacanthos	Honey Locust
Salicaceae	Populus deltoides	Cottonwood
Umbelliferae	Zizia aurea	Golden Alexander

1/ Based on USDA rating scheme.
2/ Species receiving a rating of 8 or less.
3/ Species receiving a rating of 9 or 10.
4/ Species receiving a rating of 11.

Source: W. B. Roth, I. M. Cull, R. A. Buchanan and M. O. Bagby. "Whole Plants as Renewable Energy Sources: Inventory of 508 Species Analyzed for Hydrocarbon, Oil, Polyphenol and Protein," Unpublished manuscript from the USDA Northern Regional Laboratory, Peoria, Illinois, 1982.

Table III-8. Native and naturalized Montana species with possible potential as whole-plant-oil species as determined from sources other than USDA

Family	Species	Common name
Asclepiadaceae	Asclepias pumila	Plains Milkweed
	A. speciosa	Showy Milkweed
	A. viridiflora	Green Milkweed
Asteraceae	Artemisia absinthium	Wormwood, Common Sagewort
	A. campestris	Field Sagewort
	A. dracunculus	False-tarragon Sagewort
	A. ludoviciana	Cudweed Sagewort
	Chrysothamnus viscidiflorus	Green Rabbitbrush
	Cirsium undulatum	Wavyleaf Thistle
	Grindelia nana	Low Gumweed
	G. squarrosa	Curly-cup Gumweed
	Gutierrezia sarothrae	Broom Snakeweed
	Liatris ligulistylis	Blazingstar
	L. punctata	Dotted Blazingstar
	Machaeranthera canescens	Hoary Aster
	M. grindelioides	Goldenweed
	M. tanacetifolia	Tansy Aster
	Solidago canadensis	Canada Goldenrod
	S. gigantea	Smooth Goldenrod
	S. missouriensis	Prairie Goldenrod
	Tragopogon dubius	Common Salsify
Caprifoliaceae	Symphoricarpos albus	Common Snowberry
	S. occidentalis	Western Snowberry
Chenopodiaceae	Chenopodium hybridum	Sowbane
	Kochia scoparia	Kochia, Summer Cypress
	Salsola kali	Russian Thistle
Euphorbiaceae	Euphorbia cyparissias	Cypress Spurge
	E. glyptosperma	Ridge-seeded Spurge
	E. helioscopia	Summer (Sun) Spurge
	E. hexagona	Sixangle Spurge
	E. marginata	Snow-on-the-Mountain
	E. missurica	Missouri Spurge
	E. serpens	Serpent Spurge
	E. serpyllifolia	Thyme-leaved Spurge
	E. spathulata	Spatula-leaved Spurge
Papaveraceae	Argemone polyanthemos	Prickly Poppy

Sources: DPRA survey of representatives from Native Plants, Inc. (Salt Lake City Utah) and Hesse Products Company (Reno, Nevada) September 1982; DPRA survey of taxonomists, agronomists, ecologists, weed scientists, and plant breeders from Montana State University, University of Montana, South Dakota State University, Idaho State University, and the University of Wyoming, September, 1982; S. P. McLaughlin and J. J. Hoffman, "Survey of Biocrude-Producing Plants from the Southwest," Economic Botany 36(1982, no. 3):323-339.

McLaughlin and Hoffman (1982) of the University of Arizona recently reported on screening and testing nearly 200 species from southwestern North America. Selection criteria that took into account amounts of extractable oil and hydrocarbons, estimated per-acre yields and production costs gave them eleven species of highest potential:

Pedilanthus macrocarpus	Amsonia grandiflora
Asclepias albicans	Amsonia hirtella
Asclepias subulata	Amsonia kearneyana
Asclepias erosa	Xanthocephalum gymnospermoides
Chrysothamnus paniculatus	Grindelia camporum
Chrysothamnus nauseosus	

Only one of the eleven, Chrysothamnus nauseosus (Rubber Rabbitbrush), is found in Montana. It was ranked highly by USDA as well and is already included in Table III-7. Three genera from the above list are common to Montana--Chrysothamnus, Asclepias (Milkweed), and Grindelia (Gumweed). Based on (1) the high ratings of these genera in the McLaughlin and Hoffman study and (2) input from the professionals we contacted to broaden the range of species examined, we included all Montana species in these genera for further consideration. Species not already included in Table III-7 (species from Roth, Cull, Buchanan, and Otey (1982)) were included in Table III-8.

Whole-plant analysis data were also presented for all species examined in the McLaughlin and Hoffman (1982) study. The following Montana species had hexane extracted materials (oil) of 5 percent or higher (by dry weight); Tragopogon dubius, Salsola kali, Solidago missouriensis and all members of the Euphorbia genus. Those not already included in Table III-7 were placed in Table III-8 for further consideration.

Another study in which several species were examined for potential as fuel-producing plants was conducted by the Hesse Products Company. Darrell Lemaire, the company's chief investigator, stated that seven species from the Reno, Nevada, area were examined, and two emerged with high fuel-producing potential--Chrysothamnus nauseosus (Rubber Rabbitbrush) and Gutierrezia sarothrae (Broom Snakeweed). Both are common in Montana and, thus, were included for further consideration.

In an attempt to broaden the range of species considered beyond those examined in the literature, we contacted representatives (e.g., ecologists, taxonomists, oilseed breeders, and agronomists) from the two major universities in Montana and from major universities in states surrounding Montana for suggestions on plants with whole-plant, oil-producing potential. Those mentioned most frequently were Asclepias speciosa (and the Asclepias genus in general), Euphorbia esula (and the Euphorbia genus in general), Chrysothamnus nauseosus, Grindelia squarrosa, and Gutierrezia sarothrae. Other suggestions included Liatris sp. (Blazingstar), Artemisia ludoviciana (Cudweed Sagewort), A. campestris (Field Sagewort), Cirsium undulatum (Wavyleaf Thistle), Salsola kali and members of the Papaveraceae. Based on these suggestions the following species were chosen for further consideration (most of the others already had been included from other sources):

Argemone polyanthemos (Prickly Poppy)
Artemisia absinthium (Wormwood, Common Sagewort)
Artemisia campestris (Field Sagewort)
Artemisia dracunculus (False-tarragon Sagewort)
Artemisia ludoviciana (Cudweed Sagewort)
Chenopodium hybridum (Sowbane)
Cirsium undulatum (Wavyleaf Thistle)
Liatris ligulistylis (Blazingstar)
Liatris punctata (Dotted Blazingstar)
Machaeranthera canescens (Hoary Aster)
Machaeranthera grindelioides (Goldenweed)
Machaeranthera tanacetifolia (Tansy Aster)
Solidago canadensis (Canada Goldenrod)
Solidago gigantea (Smooth Goldenrod)
Symphoricarpos albus (Common Snowberry)
Symphoricarpos occidentalis (Western Snowberry)

One additional species, Kochia scoparia, now considered a problem weed, was included because of the great interest shown in it.

b. Species retained following preliminary screening

As with oilseed species, eliminations at this stage of the study were to remove, before field sampling began, species that preliminary

evaluations indicated would likely not adapt to dryland agriculture in Montana. Information gained from floras (Booth and Wright 1968; Hitchcock and Cronquist 1973; USDA 1971; Van Bruggen 1976; Weber 1972 and Welsh 1973) and from the Montana State University herbarium was used as well as the field experience of our Montana State University consultants. Table III-9 lists species eliminated with the rationale for elimination.

Table III-10 presents species that remained after the elimination process--the species considered for sampling. No distinction was made between annuals and perennials. The latter are of great interest as whole-plant oil producers because the plant's biomass is harvested rather than just the seed and because some perennials can grow back rapidly even when clipped several times each year.

2. Yield Estimates

As with potential oilseed species, yields were not estimated for potential whole-plant-oil species. Both biotic and environmental factors interact to produce the plant spacings and biomass accumulations found in nature. Without being able to quantify those factors, valid yield estimates are impossible. For validity, such estimates must be made from a properly controlled and monitored monocultural situation.

Some information is available from earlier work (Eddleman 1977) in which the viability and suitability in reclamation areas of some 60 indigenous Montana species were assessed.

Table III-9. Native and naturalized Montana species eliminated by agronomic considerations and habitat constraints as potential whole-plant-oil species

Family	Species	Common name	Reason eliminated
Aceraceae	Acer negundo	Boxelder	Found primarily along streams; thus likely to need irrigation if cultivated
	A. platanoides	Norway Maple	Ornamental; likely need irrigation if cultivated
Anacardiaceae	Rhus glabra	Smooth Sumac	Found on SE side of Moeise Range; rocky, mesic mountain slopes; likely need irrigation if cultivated
Apocynaceae	Apocynum androsaemifolium	Spreading Dogbane	Requires moist areas; likely need irrigation if cultivated
	A. cannabinum	Indian Hemp, Hemp Dogbane	Requires shady, moist places; likely need irrigation and shade
Asclepiadaceae	Asclepias pumila	Plains Milkweed	Very small (4-25 cm); probably not produce enough biomass
	A. tuberosa	Butterfly-weed	Species primarily of Central U.S. plains; likely need irrigation when cultivated in most of Montana
Asteraceae	Ambrosia trifida	Tall Ragweed	Rare; Great Plains species; because of moisture requirements may need irrigation when cultivated
	Artemisia absinthium	Wormwood, Common Sagewort	Would likely need irrigation if cultivated
	A. dracunculus	False-tarragon Sagewort	Would likely need irrigation if cultivated
	Grindelia nana	Low Gumweed	Found in extreme western Montana; likely has temperature and perhaps moisture constraints that preclude dryland cultivation in central and eastern Montana
	Lactuca canadensis	Canada Lettuce	Rare; open woodland species; eastern portion of state; likely need irrigation in most places for cultivation
	Liatris ligulistylis	Blazingstar	Rare; likely need irrigation in most parts of Montana
	Machaeranthera canescens	Hoary Aster	Would likely need irrigation if cultivated
	M. grindelioides	Goldenweed	Would likely need irrigation if cultivated

Continued....

Table III-9. (Continued)

Family	Species	Common name	Reason eliminated
	M. tanacetifolia	Tansy Aster	Would likely need irrigation if cultivated
	Solidago canadensis	Canada Goldenrod	Would likely need irrigation if cultivated
	S. gigantea	Smooth Goldenrod	Would likely need irrigation if cultivated
	S. graminifolia	Grassleaf Goldenrod	Found primarily in extreme eastern Montana; Great Plains species; likely need irrigation for cultivation in most other locations of state
	S. missouriensis	Prairie Goldenrod	Likely need irrigation in most parts of Montana.
	Sonchus arvensis	Field Sowthistle	Found primarily along streams and in irrigated fields; likely need irrigation for cultivation in most of Montana
	S. oleraceus	Common Sowthistle	Rare; found primarily in extreme eastern part of state; likely need irrigation for cultivation elsewhere in state
Caprifoliaceae	Lonicera tatarica	Honeysuckle	Used as an ornamental; likely need irrigation in most parts of state if cultivated
	Sambucus canadensis	American Elderberry	Found primarily at higher elevations in moist forested areas
	Symphoricarpos albus	Common Snowberry	Would likely need irrigation if cultivated
	S. occidentalis	Western Snowberry	Would likely need irrigation if cultivated
Chenopodiaceae	Chenopodium hybridum	Sowbane	Would likely need irrigation if cultivated
Euphorbiaceae	Euphorbia cyparissias	Cypress Spurge	Rare in Montana; likely higher water requirements because it is a garden escape growing along roadsides; plants are small, only 10-30 cm tall
	E. glyptosperma	Ridge-seeded Spurge	Grows too close to ground (semiprostrate to decumbent), would be difficult to harvest
	E. helioscopia	Summer (Sun) Spurge	Rare; found only in extreme northwest corner of Montana (range principally eastern U.S. and west of Cascades); likely has temperature and perhaps moisture constraints that preclude dryland cultivation in central and eastern Montana

Continued....

Table III-9. (Continued)

Family	Species	Common name	Reason eliminated
	E. hexagona	Sixangle Spurge	Very rare in Montana; primarily found in the southern half South Dakota in sandy areas
	E. missurica	Missouri Spurge	From herbarium samples, plant appears small and decumbent with only a few small seeds.
	E. serpens	Serpent Spurge	Grows too close to ground (semiprostrate to decumbent) difficult to harvest; rare in Montana
	E. serpyllifolia	Thyme-leaved Spurge	Grows too close to ground (semiprostrate to decumbent) difficult to harvest
Juglandaceae	Juglans nigra	Black Walnut	Ornamental; likely need irrigation in most parts of state if cultivated
Lamiaceae	Leonurus cardiaca	Motherwort	Rare; likely need irrigation for cultivation
	Lycopus americanus	(Cut-leaved) Water Horehound	Rare; likely need irrigation in most parts of the state if cultivated
	Mentha arvensis	Field Mint	Moist areas; likely need irrigation if cultivated
	Monarda fistulosa	Horse Mint, Wild Bergamont	Prairie species; will likely need irrigation for cultivation
	Nepeta cataria	Catnip	Found mostly at higher elevations; likely need irrigation for cultivation
Leguminosae	Amorpha canescens	Lead Plant	Eastern Montana is western edge of range
	Astragalus americanus	American Milk Vetch	Found mostly along western Montana streams; may need irrigation for cultivation
	Gleditsia triacanthos	Honey Locust	Ornamental only; may need irrigation for cultivation in most parts of Montana
Salicaceae	Populus deltoides	Cottonwood	May need irrigation for cultivation in may parts of Montana
Umbelliferae	Zizia aurea	Golden Alexander	Rare; primarily central plains and Black Hills species; may need irrigation for cultivation

Source: Development Planning and Research Associates, Inc.

Table III-10. Native and naturalized Montana species retained as potential whole-plant-oil species

Family	Species	Common name	Habitat 1/
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	Moist meadows
	A. syriaca	Common Milkweed	Fields and waste places
	A. verticillata	Whorled Milkweed	Dry soil
	A. viridiflora	Green Milkweed	Prairie, sandy soil
Asteraceae	Achillea millefolium	Yarrow	Plains and mountain valleys
	Artemisia campestris	Field Sagewort	Rocky or sandy places
	A. ludoviciana	Cudweed Sagewort	Grasslands and dry lands
	Carduus nutans	Musk Thistle	Grasslands
	Chrysothamnus nauseosus	Rubber Rabbitbrush	Grasslands
	C. viscidiflorus	Green Rabbitbrush	Dry hills and plains
	Cirsium arvense	Canada Thistle	A troublesome weed
	C. undulatum	Wavyleaf Thistle	Dry plains
	Grindelia squarrosa	Curly-cup Gumweed	Moist places
	Gutierrezia sarothrae	Broom Snakeweed	Open rangeland
	Liatris punctata	Dotted Blazingstar	Grasslands
	Solidago rigida	Stiff Goldenrod	Dry prairie and plains
	Tragopogon dubius	Common Salsify	Roadsides, open places or in bunch grass rangelands
Caprifoliaceae	Symphoricarpos orbiculatus	Coralberry	Open woods, thickets, dry banks
Chenopodiaceae	Chenopodium album	Lambsquarter, White Goosefoot	Waste places
	Kochia scoparia	Kochia, Summer Cypress	Wasteland weed
	Salsola kali	Russian Thistle	Dry valleys and plains
Euphorbiaceae	Euphorbia esula	Leafy Spurge	Field and range weed
	E. marginata	Snow-on-the-Mountain	Dry plains and valleys
	E. spathulata	Spatula-leaved Spurge	Sand spots or openings in grasslands
Gramineae	Agropyron repens	Quack Grass	Roadsides
	Elymus canadensis	Canada Wildrye	Prairies and roadsides
Papaveraceae	Argemone polyanthemos	Prickly Poppy	Plains

1/ W. E. Booth and J. C. Wright, Flora of Montana, Part II, (Bozeman, Montana. Montana State University 1966): T. Van Bruggen, The Vascular Plants of South Dakota, (Ames, Iowa: Iowa State University Press, 1976).

Source: Development Planning and Research Associates, Inc.

IV. PLANT SAMPLING, TESTING, AND RESULTS

We took field samples of the native and naturalized Montana plants thought to have the most potential as seed-oil or whole-plant-oil producers, concentrating mostly on species for which no data currently exist. We also sampled many species for which data exist because most collections in existing studies were not made in Montana.

This chapter discusses methods used in plant sampling and in seed plant analyses. It also presents analyses results and ranks the potential seed-oil and whole-plant-oil species studied.

A. Methods

Potential sampling sites were selected prior to actual sampling and four major collecting trips within the area from the Rocky Mountain front (Bozeman to Shelby) east to Miles City were planned.

To locate collection sites of less common species, we consulted Dr. John H. Rumely, curator of the Montana State University Herbarium, and used plant-identification requests the University received in the last two years. The more common species were located by project personnel driving through areas where they were known to occur. Actual sampling sites were selected as species were located. When possible, three sites for each species were selected and sampled so variation in oil and protein contents between sites could be examined. Fewer sites were located for some uncommon species. More sites were sampled when either few plants per site or few plants in collectable condition per site were found; in these cases samples from several sites were combined to obtain a large enough sample for analysis. Sites could not be located for all species. Tables IV-1 (oilseeds) and IV-2 (whole-plant-oil) give the number of sites sampled for each species investigated.

The four major collection trips were:

- West from Bozeman along county roads to Three Forks and return
- Bozeman to Billings, north to Roundup, east to Miles City, and return

Table IV-1. Sites sampled for oilseed species

Family	Species	Common name	Number of sites sampled 1/	Comments
Asteraceae	Helianthus petiolaris	Prairie Sunflower	0	No sites found.
	Xanthium strumarium	Cocklebur, Cow Cockle	1	At another site plants were bulldozed before collections could be made.
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	1	--
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	7	Seeds were so few that samples from 6 sites were combined into one sample
	Descurainia pinnata	Tansymustard	0	Uncommon
	D. sophia	Flixweed	0	Uncommon
	Isatis tinctoria	Dyer's Woad	0	Rare
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	2	--
	S. loeselii	Loesel Tumble Mustard	3	--
	Thlaspi arvense	Field Pennycress, Fanweed	1	Already dispersed in most areas located.
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	2	--
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	1	--
Euphorbiaceae	Euphorbia esula	Leafy Spurge	0	Already dispersed in most areas located.
	E. marginata	Snow-on-the-Mountain	1	
	E. spathulata	Spatula-leafed Spurge	0	Rare
Loasaceae	Mentzelia decapetala	Tenpetal Blazingstar, Sand Lily	2	Samples combined into one.
Onagraceae	Gaura parviflora	Small-flowered Gaura	0	Uncommon
Papaveraceae	Argemone polyanthemos	Prickly Poppy	3	Samples combined into one.

1/ "0" indicates no sites sampled.

Table IV-2. Sites sampled for whole-plant-oil species

Family	Species	Common name	Number of sites sampled 1/	Comments
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	3	--
	A. syriaca	Common Milkweed	0	No sites found.
	A. verticillata	Whorled Milkweed	0	Rare
	A. viridiflora	Green Milkweed	0	No sites found.
Asteraceae	Achillea millefolium	Yarrow	0	No plants found in collectable condition; either too dry or already dispersed.
	Artemisia campestris	Field Sagewort	2	
	A. ludoviciana	Cudweed Sagewort	3	--
	Carduus nutans	Musk Thistle	3	--
	Chrysothamnus nauseosus	Rubber Rabbitbrush	2	--
	C. viscidiflorus	Green Rabbitbrush	0	No sites found.
	Cirsium arvense	Canada Thistle	3	--
	C. undulatum	Wavyleaf Thistle	1	--
	Grindelia squarrosa	Curly-cup Gumweed	3	--
	Gutierrezia sarothrae	Broom Snakeweed	3	--
	Liatris punctata	Dotted Blazingstar	2	--
	Solidago rigida	Stiff Goldenrod	3	--
	Tragopogon dubius	Common Salsify	2	--
Caprifoliaceae	Symphoricarpos orbiculatus	Coralberry	0	Rare
Chenopodiaceae	Chenopodium album	Lambsquarter, White Goosefoot	0	Already dispersed.
	Kochia scoparia	Kochia, Summer Cypress	3	--
	Salsola kali	Russian Thistle	2	--
Euphorbiaceae	Euphorbia esula	Leafy Spurge	1	--
	E. marginata	Snow-on-the-Mountain	1	--
	E. spathulata	Spatula-leaved Spurge	0	Rare
Gramineae	Agropyron repens	Quack Grass	2	--
	Elymus canadensis	Canada Wildrye	0	Plants already dried and shattered.
Papaveraceae	Argemone polyanthemos	Prickly Poppy	1	--

1/ "0" indicates no sites sampled.

- West from Bozeman to Three Forks, north to Shelby, east to Havre, southwest to Great Falls, southeast to Stanford, southwest to White Sulphur Springs and Livingston, and return
- West from Bozeman to Three Forks, north to Augusta, and return

Several shorter sampling trips were made in Gallatin and Park counties. During the trips, plants were collected at the 42 sites listed and described in Table A-1 of the Appendix.

To collect samples for seed oil analyses, we removed mature seeds (and often fruit) from randomly selected plants. For species that had only begun seed dispersal, plants with mature or nearly mature seed were cut at ground level for biomass samples. When possible, reproductive tissue was separated from vegatative material. In collecting plants for whole-plant oil analyses, we used the procedure the USDA's Northern Regional Research Laboratory researchers developed. Plants were cut at ground level just before seed dispersal began, being careful to use consistent procedures because USDA researchers have shown that the amount and type of oil varies with the time of year and life stage of collected plants.

Seed and whole plant samples were further prepared at Montana State University according to standard practice. All plant samples were first dried a week at 45 C in a forced air oven. Seed for analyses were separated from the other plant material, by procedures (e.g., belt or cone thrasher, air separation) that differed among plant species depending on the structure of the plants' reproductive tissue. Whole-plant samples were prepared by grinding the plant material in a hammermill (1500 rpm). The prepared samples were then shipped to Doty Laboratories for analysis.

Doty Laboratories, Inc. of North Kansas City, Mo., performed the seed and whole-plant analyses for oil, protein (N x 6.25), fiber, ash, and moisture levels. Carbohydrate levels and total digestable nutrients (T.D.N.) were calculated from these analyses results. Analyses other than oil content were run only when oil content exceeded 20 percent for seed and 3 percent for whole plant materials. Petroleum ether was used for oil extraction.

The precision for Doty Laboratories' protein analyses is 0.2. The precision for the fiber, ash, moisture and oil levels is expressed as a relative percent, i.e., a percentage of the values determined. For example, a 5 percent percision for a reported fiber level of 10.0% means 10.0 ± 0.5%. The precision of the analyses is 5 percent for fiber, 3 percent for ash, and 4 to 5 percent for moisture. The laboratory tries to maintain a 5 percent precision for oil; however, oil analyses run on the same sample may vary by as much as 10 percent depending on the type of material and its heterogenity.

Doty Laboratories require at least 100 grams of material to perform the analyses we requested. Though a much smaller subsample is required for these analyses, the larger initial sample helps assure that the laboratory receives enough material to be representative of the population sampled. The inherent material heterogenity is minimized by thoroughly mixing the original 100 gram sample before subsamples are taken.

One limitation the laboratory operated under in analyzing these seeds and plant materials was that its analysts had never worked with many of the species examined in this study. As a result, some handling difficulties were encountered initially. Procedures had to be developed, for example, to insure adequate grinding of smaller seeded species (e.g., Sisymbrium loeselii). The mill normally used to crack the seed coats to assure complete extraction did not grind smaller seeds; thus, modified procedures (finer screens) were used when preparing these samples.

B. Results and Analyses

Experimental results obtained from Doty Laboratories were converted to dry weight basis. For those samples for which only oil content was analyzed, a moisture content of 6.0 percent was estimated for the oilseeds and a 9.8 percent for the whole plants in order to convert all oil contents to a dry basis. These percentages were determined by averaging the moisture level of those samples for which total analyses were run.

The total digestable nutrient (T.D.N.) level expresses the amount of digestable organic material available to a feeding animal and was calculated by summing the oil, protein and carbohydrate levels:

$$T.D.N. = 2.25 \times \text{oil } (\%) + \text{carbohydrate } (\%) + \text{protein } (\%)$$

The oil level was multiplied by 2.25 because its energy level is 2.25 times that of protein and carbohydrates. Digestability coefficients are sometimes utilized in calculating T.D.N. These coefficients vary both by animal and nutrient type. Because we were not certain what type of animal would be utilizing the feed meal left after oil extraction, we chose not to use such coefficients. (This method for calculating T.D.N. is commonly used when the animal type using the meal is unknown.)

Carbohydrate level is the sum of the fiber content and the nitrogen free extract. It may be obtained directly through chemical analysis; for this study it was determined as the difference of the oil, fiber, protein, ash, and moisture percentages that were obtained through chemical analyses.

The results and conclusions for the oilseed and whole-plant-oil plants are presented below in separate sections.

1. Potential Oilseed Plants

This section contains two subsections. The first examines seed analyses results and the second attempts a preliminary species grouping reflecting potential as seed-oil producing plants. The latter also includes a detailed discussion of each species.

a. Overall results

Table IV-3 presents the seed-analysis results for the species sampled in this study. Species highest in oil content are *Argemone polyanthemos* (36.0 percent), *Sisymbrium altissimum* (32.2 and 28.4 percent for the two sites sampled), *Mentzelia decapetala* (28.5 percent) and *Euphorbia marginata* (25.6 percent). Those with lowest oil contents are *Kochia scoparia* (8.2 percent) and *Xanthium strumarium* (10.0 percent). For one species, *Sisymbrium loeselii*, two of the three field

Table IV-3. Seed-analysis results for potential oilseed species 1/

Family	Species	Common name	Site identification number	Percentages: Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash	Plant part analyzed
Asteraceae	Helianthus petiolaris	Prairie Sunflower	No sites located	-	-	-	-	-	-	--
	Xanthium strumarium	Cocklebur, Cow Cockle	23	10.0	-	-	-	-	-	Seed and pericarp
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	7, 12	18.2	-	-	-	-	-	Seed
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	Multiple 4/	24.6	27.6	43.9	126.9	17.4	3.9	Seed
			21	23.3	26.2	47.8	126.4	37.7	2.7	Seed
	Descurainia pinnata	Tansymustard	No sites located							
	D. sophia	Flixweed	No sites located							
	Isatis tinctoria	Dyer's Woad, Yellow Woad	No sites located							
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	15	28.4	34.7	33.2	131.7	7.9	3.7	Seed
			28	32.2	29.8	33.9	136.2	7.8	4.1	Seed
	S. loeselii	Loesel Tumble Mustard	1	27.9	29.5	39.8	131.9	14.9	2.9	Seed
			4	35.6	31.1	30.1	141.5	5.3	3.1	Seed
			15	17.7	30.3	48.7	118.6	35.2	3.5	Seed
	Thlaspi arvense	Field Pennycress, Fanweed	13	24.0	26.6	43.7	124.3	10.0	5.7	Seed
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	11	23.3	23.5	49.8	125.7	32.3	3.4	Seed
			22	18.8	-	-	-	-	-	Seed
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	1	8.2	-	-	-	-	-	Seed
Euphorbiaceae	Euphorbia esula	Leafy Spurge	No sites located							
	E. marginata	Snow-on-the-Mountain	24	25.6	17.6	51.7	126.9	23.5	5.1	Seed
	E. spathulata	Spatula-leaved Spurge	No sites located							

Continued...

Table IV-3. (Continued)

Family	Species	Common name	Site identification number	Percentages						Plant part analyzed
				Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash	
Loasaceae	_Mentzelia decapetala_	Tenpetal Blazingstar, Sandy Lily	29,30	28.5	19.0	39.0	122.1	17.3	13.5	Seed
Onagraceae	_Gaura parviflora_ 2/	Small-flowered Gaura	No sites located							
Papaveraceae	_Argemone polyanthemos_	Prickly Poppy	18,19,20	36.0	17.4	41.6	140.0	11.7	5.0	Seed

1/ All data were calculated on a dry weight basis. When oil content was below 20 percent, no other tests were run.

2/ Includes fiber and nitrogen-free extract.

3/ T.D.N. - total digestible nutrients. Following procedures of Doty Laboratories, Inc., we assumed no digestibility coefficients in calculating T.D.N. (i.e., T.D.N. = 2.25 x oil (%) + carbohydrates (%) + protein (%)). Thus, this T.D.N. expresses the total potential nutrients available in the seed. See text page 56 for further explanation.

4/ Includes sites 3, 4, 7, 8, 9,and 16.

Source: Research by Development Planning and Research Associates, Inc.

samples had one of the highest (35.6 percent) and one of the lowest (17.7 percent) oil levels. The third sample's oil level was 27.9 percent.

Table IV-4 gives comparative oil contents reported in USDA studies. Theirs were strikingly higher than ours. The difference may stem from geographic and weather factors. Field sampling might have also entered in. The maturity of plants may have differed between the two studies as well as methods used to sample plant populations.

Georing, Eslick and Brelsford also reported oil levels higher than ours for certain species (Table IV-4). But they tested seeds from mustards grown under controlled agricultural conditions while ours were from natural populations subjected to more stress. Original seeds for the mustards that Georing, Eslick, and Brelsford sampled were from USDA seed accessions and, thus, are possibly from populations related to those used in the USDA research.

Species with highest protein content contents are Sisymbrium altissimum, 34.7 and 29.8 percent for the two sites sampled; Sisymbrium loeselii, 31.1, 30.3, and 29.5 percent for the three sites sampled; Camelina microcarpa, 27.6 and 26.2 percent for the two sites sampled; and Thlaspi arvense, 26.6 percent (Table IV-3). Those with lowest protein content are Euphorbia marginata, (17.6 percent), and Argemone polyanthemos (17.4 percent).

To help assess feed quality, we also determined carbohydrate levels and total digestible nutrients (T.D.N.) (Table IV-3). Such data for cultivated oilseed species (cottonseed, soybeans and sunflowers), which are producers of high quality seed meal, are shown in Table IV-5. All Montana species examined with oil contents above 20 percent 1/ (Table IV-3) have protein, carbohydrate and T.D.N. that compare favorably with cottonseed, soybeans, and sunflowers. All protein levels are near or above that of sunflower seed, with hulls (17.9 percent). Carbohydrate levels ranged from 39.0 to 54.9 percent, well above that of soybeans (33.7 percent) and in the same range as cottonseed (46.6 percent) and

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1/ We did no additional seed analyses on species with lower oil levels.

Table IV-4. Seed-analysis data for species considered potential oilseed crops

Family	Species	Common name	Oil levels (%) USDA 1/ 2/	DPRA 2/ 3/	Georing et al. 4/5/
Asteraceae	Helianthus petiolaris	Prairie Sunflower	24.1-32.5 6/	-	
	Xanthium strumarium	Cocklebur, Cow Cockle	35.7-38.2	10	
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	-	18.2	28.9
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	34.1	23.3-24.6	27.5
	Descurainia pinnata	Tansymustard	38.4	-	32.8
	D. sophia	Flixweed	26.9-39.7	-	30.4
	Isatis tinctoria	Dyer's Woad	32.9-37.4	-	-
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	35.2-35.9	28.4-32.2	23.5
	S. loeselii	Loesel Tumble Mustard	-	17.7-35.6	30.0
	Thlaspi arvense	Field Pennycress, Fanweed	28.2-32.9	24.0	26.7
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	28.6-33.6	18.0-23.3	-
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	8.8-11.2	-	-
Euphorbiaceae	Euphorbia marginata	Snow-on-the-Mountain	31.7-32.0 6/	25.6	-
Loasaceae	Mentzelia decapetala	Tenpetal Blazingstar, Sand Lily	37.0-42.4	28.5	-
Onagraceae	Gaura parviflora	Small-flowered Gaura	13.7-41.2 6/	36.0	-
Papaveraceae	Argemone polyanthemos	Prickly Poppy	36.2		

1/ Sources: A. S. Barclay and F. R. Earle, "Chemical Analyses of Seeds III: Oil and Protein Content of 1,253 Species," Economic Botany 28(1974):178-236; F. R. Earle and Quentin Jones, "Chemical Analyses of Seeds II: Oil and Protein Content of 759 Species," Economic Botany 20(1966):127-155; Quentin Jones and F. R. Earle, "Analyses of Seed Samples From 113 Plant Families," Economic Botany 16(1962):221-250.

2/ Petroleum ether extraction.

3/ Source: Research by Development Planning and Research Associates, Inc.

4/ Source: K. J. Goering, Robert Eslick and D. L. Brelsford, "A Search For High Erucic Acid Containing Oils in the Cruciferae," Economic Botany 19(1965):251-256.

5/ Hexane extraction.

6/ Both seed and pericarp were extracted.

Table IV-5. Seed analysis data for cultivated oilseed species also considered producers of high quality seed meal

Plant	Oil	Protein (NX6.25)	Carbohydrates 1/	T.D.N. 2/	Fiber	Ash
	percent					
Cottonseed 3/ (seeds ground)	24.7	24.9	46.6	127.0	18.2	3.8
Soybeans 3/ (seeds ground)	19.2	41.7	33.7	118.6	5.8	5.4
Sunflower Seeds 4/ (seeds ground, hulls included)	27.7 5/	17.9	51.1	131.3	31.0	3.3

1/ Includes fiber and nitrogen free extract.

2/ T.D.N. = total digestible nutrients. We assumed no digestibility coefficients in calculations (i.e., T.D.N. = 2.25 x oil (%) + carbohydrates (%) + protein (%)). Thus, the T.D.N. expresses the total potential nutrients available in the seed. See text page 56 for further explanation.

3/ Source: A. E. Cullison, Feeds and Feeding, (Reston, Va.: Reston Publishing Company, Inc., 1982).

4/ Source: E. S. Lipinsky, T. A. McClure, S. Kresovich, J. L. Otis, C. K. Wagner, D. A. Trayser and H. R. Applebaum, Systems Study of Vegetable Oils and Animal Fats for Use as Substitute and Emergency Diesel Fuels, Battelle, Columbus, Ohio Laboratories, for the U.S. Department of Energy, 1981.

5/ Seed without hulls can contain 22-61 percent oil.

Source: Development Planning and Research Associates, Inc.

sunflower (51.1 percent). T.D.N. levels for Montana species we examined ranged from 118.6 to 141.5 percent which is in the same range with soybeans (118.6 percent), cottonseed (127.0 percent) and sunflower seed (131.3 percent).

Because plants may be poisonous to animals, both toxicity information and field observations are given in Table IV-6. Most of the species contained some toxin and several seemed to have agronomic difficulties.

b. Preliminary species grouping

Species examined in this study were placed in priority groupings to help the Montana DNRC direct further research on native and naturalized Montana species with potential as oilseed plants. Ranking according to oil content (Table IV-7) gave the following initial grouping:

Initial priority grouping	Oil level, %
High	> 25
Medium	> 20, but ≤ 25
Low	≤ 20

After the initial priority grouping, we considered undesirable agronomic characteristics to reduce a species' grouping by ½ to 1 level, depending on its severity. Agronomic characteristics considered included shattering, small plant size (i.e., small yields and little plant biomass for a breeder to work with to produce better yields), allelopathic chemicals that might disrupt crop rotation, susceptibility to insect damage, and moisture requirements restricting where plants may be cultivated. Unfavorable toxicity characteristics included potentially high toxicity and difficulty in removing toxin from seed meal. Seed nutrient levels (i.e., protein, T.D.N., and carbohydrates), though considered, did not affect priority grouping greatly because sampled species with more than 20 percent seed oil had nutritional levels equal to or exceeding that of sunflower seed.

Table IV-6. Possible agronomic and toxicity problems of species considered potential seed-oil producers

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
Asteraceae	Helianthus petiolaris	Prairie Sunflower	--	--	--	--
	Xanthium strumarium	Cocklebur, Cow Cockle	Pericarp may be difficult to separate from seeds	Hydroquinone	Seeds, seedlings	Seeds tend to be less toxic than seedling; 400-500 seedlings can kill a 200 lb pig.
Brassicaceae	Brassica kaber	Wild Mustard, Charlock	Moisture requirements may restrict production area; grown plants tend to be no more than 5 dm high	Mustard oil glycosides	All parts	Glycosides may be removed by enzymes and other processing techniques.
	Camelina microcarpa	Smallseed Falseflax, Hairy Falseflax	Shattering may be a problem	Mustard oil glycosides	Seeds	Glycosides may be removed by enzymes and other processing techniques.
	Descurainia pinnata	Tansymustard	--	Unknown, glycosides possibly	All parts	The unknown toxin produces symptoms like those of selenium poisoning though the plant contains little selenium. Symptoms differ from those associated with other mustards.
	D. sophia	Flixweed	--	Unknown glycosides possibly	All parts	The unknown toxin produces symptoms like those of selenium poisoning though the plant contains little selenium. Symptoms differ from those associated with other mustards.
	Isatis tinctoria	Dyer's Woad, Yellow Woad	Moisture requirements may restrict production area; plants are short; rare in Montana	May contain mustard oil glycosides	Seeds	This species was not identified specifically as containing these toxins but these toxins are characteristic of the mustard family so the probability is high that plants of this species have them.

Continued....

Table IV-6. (Continued)

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
	Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	Though numerous, seeds are very small	Mustard oil glycosides	Seeds	Glycosides may be removed by enzymes and other processing techniques.
	S. loeselii	Loesel Tumble Mustard	Shattering; numerous, very small seeds	Mustard oil glycosides	Seeds	Glycosides may be removed by enzymes and other processing techniques.
	Thlaspi arvense	Field Pennycress, Fanweed	Plants are small, 3-4 dm high	Allyl isothiocyanale	Seeds	Can be quite toxic.
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	Pod production is indeterminant and pods often drop before plant matures; appears very susceptible to insect damage	--	--	--
Chenopodiaceae	Kochia scoparia	Kochia, Summer Cypress	--	Oxalates 3/	Leaves, seeds	Can be quite toxic, but animals tolerate low levels of this toxin. Washing with water may reduce toxin in seed.
			--	Nitrates	Seeds and vegetative tissue	Can be toxic, but animals tolerate low levels of this toxin. Washing with water may reduce toxin in seed.
			--	Saponins	Seeds	Can be extracted with hexane or ethanol.
Euphorbiaceae	Euphorbia esula	Leafy Spurge	Noxious weed; may be hard to eradicate after cultivation because it reproduces by rhizomes and its seed is dispersed by birds	Acrid principle	All parts	Acrid principle toxin is characteristic of this genus, but toxicity varies by species. E. esula does not appear to be as toxic as other Euphorbia species since there are reports of it being successfully fed to sheep.

Continued....

Table IV-6. (Continued)

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
	E. marginata	Snow-on-the-Mountain	--	Acrid principle	All parts	All parts are poisonous to some extent. The milky juice may cause dermatitis with blisters. The acrid toxin is not destroyed by drying. Livestock find plants unpalatable.
	E. spathulata	Spatula-leaved spurge	--	Acrid principle	All parts	All parts are poisonous to some extent. The milky juice may cause dermatitis with blisters. The acrid toxin is not destroyed by drying. Livestock find plants unpalatable.
Loasaceae	Mentzelia decapetala	Tenpetal Blazingstar, Sandy Lily	Pod production is indeterminant and seeds are readily wind dispersed; seeds are small; seed weight low relative to vegetative tissue	--	--	--
Onagraceae	Gaura parviflora	Small-flowered Gaura	--	--	--	--
Papaveraceae	Argemone polyanthemos	Prickly Poppy	--	Alkaloids	All parts	This group of toxins is associated with the poppy family. This species may or may not contain toxin in levels toxic to livestock.

1/ From file observations of DPRA research team. Agronomic problems (e.g., germination, allelopathy) other than those given may exist for the listed species; however, none was readily apparent from field observation.

2/ From: H. D. Fuehring, "Kochia as a Forage Crop," unpublished paper from New Mexico State University Plains Branch Station, Clovis, N. M., 1982; H. A. Stephens, Poisonous Plants of the Central United States, (Lawrence, Kans.: The Regents Press of Kansas, 1980); G. D. Buck, G. A. Osweiler and G. A. Gelder, Clinical and Diagnostic Veterinary Toxicology, (Dubuque, Iowa: Kendall/Hunt Publishing Company, 1973); E. C. M. Coxworth, J. M. Bell and R. Ashford, "Preliminary Evaluation of Russian Thistle, Kochia and Garden Atriplex as Potential High Protein Seed Crops for Semiarid Areas, Canadian Journal of Plant Science 49(1968):422-434; L. D. Hulbert and F. W. Oehme, Plants Poisonous to Livestock, (Manhattan, Kansas: Kansas State University, 1968); W. F. Booth and J. C. Wright, 1966. Flora of Montana, (Bozeman, Montana: Montana State University, 1966); W. C. Muenscher, Poisonous Plants of the United States, (New York: Macmillan Company, 1948); conversations with veterinary toxicologist, animal scientist, and agronomist at Kansas State University (1982).

3/ Ruminants are less susceptible to oxalate because most of it is metabolized in the rumen. Ruminants can eat much more oxalate-containing plants without being affected than nonruminants can.

Table IV-7. Ranking of sampled species by oil content

Species	Common name	Oil	Initial priority grouping
		(%)	
Argemone polyanthemos	Prickly Poppy	36.0	High
Sisymbrium loeselii	Loesel Tumble Mustard	35.6	High
Sisymbrium altissimum	Jim Hill Mustard, Tumble Mustard	32.2	High
Mentzelia decapetala	Tenpetal Blazingstar Sand Lily	28.5	High
Euphorbia marginata	Snow-on-the-Mountain	25.6	High
Camelina microcarpa	Small Seed Falseflax, Hairy Falseflax	24.6	Medium
Thlaspi arvense	Field Pennycress, Fanweed	24.0	Medium
Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	23.3	Medium
Brassica kaber	Wild Mustard Charlock	18.2	Low
Xanthium strumarium	Cocklebur, Cow Cockle	10.0	Low
Kochia scoparia	Kochia, Summer Cypress	8.2	Low

1/ Note the highest oil content found for each species was used to rank the species.

Source: Development Planning and Research Associates, Inc.

We included species in the priority grouping not found in our sampling efforts. Those included, while uncommon, have high oil contents reported by others and should not be eliminated because we could not find them. Their uncommonness does not necessarily mean that they would not do well in Montana. Both competition and seed dispersal characteristics could keep plant abundance down or absent. But, agricultural situations can be altered to enhance a plant's growth and reproduction.

Table IV-8 presents the preliminary priority grouping. Species in the highest priority grouping are: Argemone polyanthemos, Euphorbia marginata, Sisymbrium altissimum, Helianthus petiolaris, Euphorbia spathulata, Gaura pariflora and Isatis tinctoria. The last four are among those we could not find. Our secondary data sources indicate that those four may have very high potentials, and we found no agronomic or toxicity problems to lower their priority. Species of lowest interest are Brassica kaber, Kochia scoparia, and Thlaspi arvense.

Sampling results, agronomic problems, toxicity and other factors considered in the priority groupings follow, with species arranged in alphabetical order.

Argemone polyanthemos (Prickly Poppy) - This species' oil level, 36 percent, is among the highest of those tested (Table IV-3), and is close to the USDA researchers' report of 36.2 percent (Table IV-4). The protein level (17.4 percent, Table IV-3) is much lower than that for either cottonseed or soybeans, but only slightly lower than sunflower (Table IV-5). Prickly Poppy's T.D.N. (140.0 percent, Table IV-3) is high, due to the oil content of its seed, and is higher than that of cottonseed, soybeans, or sunflower seed.

In field observations Prickly Poppy seemed to have no major agronomic difficulties but seed yields, as percentages of total plant dry weight (14.9 grams, average), were only 6 and 12 percent (Table IV-9) for the two sites sampled, so seed yields may have to be improved

Table IV-8. Preliminary priority grouping of native and naturalized species considered potential oilseed crops

Priority grouping	Species	Common name	Comments
High interest	*Argemone polyanthemos*	Prickly Poppy	Oil levels are very high and seed nutritional levels appear good. Concerns are seed yields and possible toxins in the meal.
High interest	*Euphorbia marginata*	Snow-on-the-Mountain	Oil and nutrient levels make species attractive as an oil seed plant but the seed meal's potential toxicity should be examined carefully.
High interest	*Euphorbia spathulata*	Spatula-leafed Spurge	No seed-analysis data are available for this species. Because of high oil and protein levels associated with the *Euphorbia* genus, it definitely should be examined further. Reasons for this species rareness in Montana should be examined carefully and the potential toxicity of its seed meal.
High interest	*Gaura parviflora*	Small-flowered Gaura	Oil and protein data from secondary sources warrant further research. Reasons for the species rareness in Montana should be examined carefully.
High interest	*Isatis tinctoria*	Dyer's Woad	Oil and protein data from secondary sources indicate that this species should be examined further. Moisture requirements should be examined because they could be too high for dryland farming.
High interest	*Helianthus petiolaris*	Prairie Sunflower	Secondary sources indicate good oil levels, but below other species in this priority grouping.
High interest	*Sisymbrium altissimum*	Jim Hill Mustard, Tumble Mustard	This species' high oil levels give it a high priority for further research. Toxicity characteristics should be examined carefully.
Medium interest	*Camelina microcarpa*	Smallseed Falseflax, Hairy Falseflax	Medium oil levels, and high protein levels. Shattering could be a problem. Seed meal contains a toxin that can be removed with proper processing.
Medium interest	*Descurainia pinnata*	Tansymustard	Secondary sources indicate very high oil and protein levels, but plants tend to be small, indicating potential yield problems. Unknown toxin associated with species may cause feeding problems.
Medium interest	*Descurainia sophia*	Flixweed	Secondary sources indicate very high oil and protein levels, but plants tend to be small, indicating potential yield problems. Unknown toxin associated with species may cause feeding problems.

Continued....

Table IV-8. (Continued)

Priority grouping	Species	Common name	Comments
Medium interest	Mentzelia decapetala	Tenpetal Blazingstar, Sand Lily	Oil level is high but, shattering and indeterminant pod development could be a problem. Seeds have special structures for wind dispersal and are readily lost from the pods. Seeds are small and yields appear low relative to total plant weight. Seeds mature very late in season, so losses can result due to freezing.
Medium interest	Sisymbrium loeselii	Loesel Tumble Mustard	Though the oil levels of this species can be very high, its severe shattering problem will make cultivating this species difficult.
Medium interest	Xanthium strumarium	Cocklebur, Cow Cockle	Though oil and protein levels are potentially quite high 1/, possible seed handling problems and high seed meal toxicity should be examined carefully.
Low to medium interest	Cleome serrulata	Rocky Mountain Bee Plant, Stinkweed	Oil content falls in the low to medium range of species examined. Indeterminant pod productions, shattering, and insect predation are of concern. Feed quality appears good.
Low to medium interest	Euphorbia esula	Leafy Spurge	Though oil content are potentially quite high, eradication problems make this species of less interest.
Low interest	Brassica kaber	Wild Mustard, Charlock	Oil levels are low. Plants are small and water requirements may restrict where they can grow.
Low interest	Kochia scoparia	Kochia, Summer Cypress	Low oil levels and potential problems with allelopathy make this species of low interest. It contains several toxins.
Low interest	Thlaspi arvense	Field Pennycress, Fanweed	Oil levels do not appear high enough to balance difficulties caused by plant's small size and apparent toxicity.

1/ We analyzed the seed and pericarp and resulting oil and protein levels were very low. Secondary sources analyzed seed only. Results indicate high oil and protein levels.

Source: Development Planning and Research Associates, Inc.

Table IV-9. Biomass measurements of selected species considered potential oilseed plants

Family	Species	Common name	Site number	Average total 1/ dry weight	Vegetative material		Reproductive material other than seeds		Seeds	
					Average dry weight	as % of total wt.	Average dry weight	as % of total wt.	Average dry weight	as % of total wt.
				(grams/plant)	(grams/plant)	(%)	(grams/plant)	(%)	(grams/plant)	(%)
Asteraceae	Xanthium strumarium	Cocklebur Cow Cockle	23	16.0	9.7	61	-	-	6.3 2/	39 2/
Brassicaceae	Sisymbrium loeselii	Loesel Tumble Mustard	4	42.9	16.4	38	23.4	55	3.1	7
			17	45.9	13.5	29	26.1	57	6.3	14
	Thlaspi arvense	Field Pennycress, Fanweed	13	1.9	1.5	78	-	-	.43	22
Capparidaceae	Cleome serrulata	Rocky Mountain Bee Plant	11	27.4	20.4	74	-	-	7.1	26
			22	-	-	79	-	-	-	21
Euphorbiaceae	Euphorbia marginata	Snow-on-the-Mountain	24	13.5	11.1	81	1.7	13	.77	6
Papaveraceae	Argemone polyanthemos	Prickly Poppy	18	10.0	7.2	72	2.2	22	.66	6
			19	19.8	11.0	56	6.4	32	2.4	12

1/ Above ground biomass only.

2/ Both seeds and pericarp.

Source: Development Planning and Research Associates, Inc.

for this plant to be considered further as an oilseed crop. 2/ Although members of the Papaveraceae family often contain alkaloids that may be toxic if the seed meal is fed to livestock (Stephens 1980) 3/, the high oil and nutritional levels of this species' seed give it high priority for further research.

Brassica kaber (Wild Mustard, Charlock) - Our seed analysis shows an oil level of 18.2 percent (Table IV-3) for this mustard, below the 20-percent cutoff, so no other tests were run on the seeds. Georing, Eslick, and Brelsford (1965) reported an oil level of 28.9 percent (Table IV-4) which is below that of some of the other mustards we examined.

Shattering will likely not be a problem for this species because most seed pods had not opened even though plants had already dried and lost their leaves before they were sampled. Plants are small, with those sampled usually less than 5 dm tall. Also wild mustard is found primarily near irrigated fields and along roadsides, so yields may not be adequate in nonirrigated fields.

B. kaber's seed meal may contain mustard oil glycosides (Table IV-6), which can cause livestock gastroenteritis, irritation of the mouth, salivation, diarrhea, and difficulty in breathing, and in severe cases, paralysis of the heart and lungs (Stephens 1980). Toxins likely can be removed by proper processing because they have been removed from some of the cultivated members of this family (Princen 1979). Still this mustard rates a low priority for further research.

Camelina microcarpa (Smallseed Falseflax, Hairy Falseflax) - Oil levels for this species are mid-range (24.6 and 23.3 percent for the two samples) of the species examined (Table IV-3), and much lower than

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2/ There could be other unapparent agronomic difficulties (seed germination, allelopathy, etc.), but too few data are available for a judgment.

3/ Fredrick W. Oehme 1982: personal communication.

USDA's 34.1 percent (Table IV-4), but close to Georing, Eslick, and Brelsford's (1965) 27.5 percent (Table IV-4). The difference may be due to geography, as our values and those of Georing et al. (1973) were made on plants grown in Montana, while the USDA sampled in Illinois and Wisconsin, or to time of sampling, as we collected seeds late in the season.

Protein levels for C. microcarpa are the highest of any species examined, 27.6 and 26.2 percent for two samples analyzed (Table IV-3), below those of soybeans but above cottonseed and sunflower (Table IV-5). C. microcarpa's highest carbohydrate and T.D.N. levels (47.8 and 126.9 percent, respectively), are comparable to those of sunflower and cottonseed.

Plants range from 4 to 9 dm tall (Booth and Wright 1966). Biomass was not collected for this species as most seeds had been dispersed by late August when sampling began, so whether shattering is a problem was not ascertained.

This species' seed meal may contain mustard oil glycosides, which can produce symptoms like those outlined for Brassica kaber (Hulbert and Oehme 1968) and which can be removed by careful processing (Princen 1979).

Because C. microcarpa's oil content is in the medium range and because its protein, carbohydrate, and T.D.N. levels compare favorably with cottonseed and sunflower seeds, it should be investigated further as an oilseed crop.

Cleome serrulata (Rocky Mountain Bee Plant, Stinkweed) - At two sites, sampled oil levels were 18.8 and 23.3 percent (Table IV-3). USDA's higher estimates (28.6-33.6 percent, Table III-4) also varied rather widely.

We had analyses run other than oil content on only one sample. Its protein content was 23.5 percent, above sunflower's 17.9 percent and near cottonseed's 24.9 percent. Cleome serrulata's carbohydrate levels (49.8 percent) and T.D.N. (125.7 percent) are close to those of cottonseed and sunflower (Table IV-5).

Plants produce seed in quantity, about 23.5 percent (Table IV-9) of the plant's total above-ground dry weight. Pod production is

indeterminant and pods often drop off before the plant matures. Plants appear to be highly susceptible to insect damage.

Stinkweed's medium oil content and its possible agronomic difficulties give it a lower priority than many other plants examined.

Descurainia pinnata (Tansymustard) - This species is less common than others reported in this study. We found no Montana sampling sites but the USDA and Georing et al. (1965) reported seed oil levels of 38.4 and 32.8 percent, respectively (Table IV-4), which put it among the species with highest oil contents. They reported protein levels of 24.4 and 35.3 percent, respectively, equal to or better than cottonseeds (24.9 percent) and above sunflower (17.9 percent).

Unfortunately plants are small, only 4 dm. tall (Booth and Wright 1968), so yields may be both inadequate and difficult to increase through plant breeding. Kansas State University plant breeders indicate that size is one of the harder characteristics to alter genetically unless size varies widely in the species.

All parts of Tansymustard are poisonous but the toxin is not definitely known (Table IV-6). Symptoms resulting from it are similar to those of selenium poisoning but this mustard contains little selenium. Symptoms include blindness, aimless wandering, and a paralyzed tongue, so affected animal's are unable to eat or drink (Stephens 1980). It is not known if the toxin can be removed by proper processing, or whether the seed meal also contains the oil glycosides, as discussed under Brassica kaber.

Though both oil and protein levels are potentially high for this species, potential toxicity and possible low yields from the small plants put it in the medium priority group.

Descurainia sophia (Flixweed) - No sites were located for this uncommon mustard, but it should be considered further because USDA workers report both high oil and protein levels at 26.9 to 39.7 and 25.5 to 29.9 percent, respectively. And Georing, Eslick, and Brelsford (1965) reported 30.4 and 26.8 percent, respectively.

Unfortunately, plants of this species grow only 4 dm tall (Booth and Wright 1966) so its yields may be inadequate and difficult to adjust through breeding, lacking biomass for significant yield adjustments.

This species has toxins like those of Descurainia pinnata (Stephens, 1980, and Hulbert and Oehme, 1968). Consequently, D. sophia was placed in the medium priority group despite its potentially high oil and protein contents.

Euphorbia esula (Leafy Spurge) - We were not able to obtain Leafy Spurge seed for analysis. Unfortunately, USDA did not examine this species; however, oil levels are likely high since other members of this genus have high seed oil levels. Preliminary results of work currently in progress indicate high oil levels (Wiatr 1983).

Members of the Euphorbia genus contain an acrid toxin that severely irritates the mouth, throat, and stomach. So cattle find these plants unpalatable (Stephens 1980; Oehme and Hulbert 1968). Though deaths are rare, emaciation, vomiting, diarrhea and weakness can result. E. esula, however, does not appear to be as toxic as some other members of this genus since studies indicate sheep tolerate and may even show a preference for this species (Christensen et al. 1938; Helgeson and Thompson 1939; Johnston and Peake 1960; Langraf, Fay, and Havstad 1982).

E. esula is classified by the State of Montana as a noxious weed making it illegal to allow plants to go to seed. Consequently, Montana law would have to be changed to allow large scale cultivation. Plants may be difficult to eradicate from a field once they are cultivated because they reproduce by rhizomes. Seeds are also readily dispersed by birds.

Though Leafy Spurge's seed oil content is potentially high the eradication problems and its current status under Montana law make it of low to medium interest for further study.

Euphorbia marginata (Snow-on-the-Mountain) - This species' oil level (25.6 percent, Table IV-3) was among the highest of the species we tested, confirming USDA estimates of 31.7 to 32.0 percent (Table IV-4). Its protein level (17.6 percent, Table IV-3) was among the lowest, close to that of sunflower (17.9 percent) but lower than cottonseed (24.9

percent), or soybeans (41.7 percent) (Table IV-5). E. marginata's carbohydrate levels (51.7 percent, Table IV-3) and T.D.N. (126.9 percent, Table IV-3) are comparable to sunflower seeds and equal to or higher than cottonseed or soybeans (see Table IV-5).

As with other members of the Euphorbia genus, E. marginata contains an acrid toxin that severely irritates the mouth, throat, and stomach making it unpalatable (Stephens 1980; Oehme and Hulbert 1968). Seeds have very little milky sap so they may be more palatable and less toxic. 4/

The oil and nutritional levels of this species' seed give it a high priority for further investigation including investigation of the meal's potential toxicity.

Euphorbia spathulata (Spatula-leafed Spurge) - This plant is rare in Montana; no sites were located for sampling, and other seed analyses are not available. But the high oil levels associated with the Euphorbia genus give E. spathulata high priority for further investigation. The reasons for the species' rareness in Montana should be examined carefully as should the potential toxicity of the seed meal (see E. esula and E. marginata).

Gaura parviflora (Small-flowered Gaura) - This Gaura is uncommon in Montana; no sites were located for sampling. USDA data show a wide range of oil levels, from 13.7 to 41.2 percent (Table IV-4) and protein levels from 11.4 to 30.6 percent. It contains no known toxins 5/ and yields are likely good as plants are 4.5-8 dm tall and produce numerous flowers (Booth and Wright, 1966). This plant should be given a high priority for further research with reasons for its rareness in Montana examined carefully.

Helianthus petiolaris (Prairie Sunflower) - No sampling sites were located for this species. USDA data (Table IV-4) show oil levels of 24.1 to 32.5 percent and protein levels of 16.9 to 22.6 percent, lower

4/ Lloyd Hulbert 1982: personal communication.

than cottonseed (24.9 percent) and soybeans (41.7 percent), but similar to those of cultivated sunflowers at 17.9 percent (Table IV-5).

We could find no evidence of any poisonous properties 5/ (Stephens 1982; Buck, Osweiler, and Gelder 1973; Hulbert and Oehme 1968). A potential agronomic problem is late maturing seeds, but that can be altered through breeding.

This species should be given a high priority for further research. No data now exist specifically for Montana populations.

Isatis tinctoria (Dyer's Woad) - This species is uncommon to rare in Montana; we found none to sample. USDA workers report high levels of both oil and protein, 32.9 to 37.4 percent and 34.0 to 38.4 percent, respectively, which compare favorably with cottonseed, soybean and sunflower (Table IV-5).

Plants are 5 to 10 dm tall and can be either annual or biennial (Van Bruggen, 1976; Booth and Wright, 1966). Found primarily along roadsides, this species' moisture requirements may require irrigation in Montana. Since Dyer's Woad is a member of the Brassicaceae, its seed meal likely contains mustard oil glycosides, which are toxins discussed in detail under Brassica kaber. Still its potentially high oil and protein levels warrant further investigation since no data are available for Montana populations. But its moisture requirements should be examined carefully.

Kochia scoparia (Kochia, Summer Cypress) - Kochia's oil level (8.2 percent) is the lowest of any species examined. This confirms research by Georing, Eslick and Brelsford (1965) and by Coxworth, Bell and Ashford (1973) who have reported oil levels of 8.8 to 11.2 and 12.4 to 14.5 percent, respectively.

5/ Much of what is known about plants poisonous to livestock has come from observations on range grazing. A species not known as poisonous could be poisonous but avoided by livestock. So large amounts should not be fed to animals until the seeds have been tested.

The seed meal contains toxins--oxalate, nitrate, and saponin--but the first two can be removed by water washing, and the last can be extracted with hexane or ethanol (Coxworth, Bell and Ashford 1968).

Kochia may have allelopathic effects on the immediately succeeding crop. Fuehring (1982) reported that wheat or grain sorghum under limited irrigation immediately after Kochia had very restricted root growth and yielded only one-third of normal in 1980. He stated that leaving a field fallow one year would likely eliminate that problem, since in 1981, a wet year, no such effect was apparent.

This species' low oil level and its potential allelopathy problems give it very low priority for further consideration as an oilseed crop.

Mentzelia decapetala (Tenpetal Blazingstar, Sand Lily) - This species' oil level, 28.5 percent, is among the highest tested (Table IV-3), but is well below the USDA researchers' report of 37.0 to 42.4 percent. The protein level (19.0 percent) is lower than that for soybeans or cottonseeds, but is above sunflower seeds (Table IV-5). Sand Lily's T.D.N. (136.2 percent, Table IV-3) is high because of the oil content of the seed and is higher than that of cottonseed, soybeans or sunflower seeds (Table IV-5).

Pod production is indeterminant and seeds are readily wind dispersed. Seeds are quite small; biomass weighings were not conducted because of the poor condition of plants after frost. Field observations indicate that seed yield is low relative to the size of individual plants; however, the plant's size indicates that seed yields could be improved by plant breeders.

Although the oil level for this species is high, its potential agronomic problems make it of less interest than other species with high oil content. Consequently this species was assigned to the medium priority grouping.

Sisymbrium altissimum (Jim Hill Mustard, Tumble Mustard) - This Mustard's oil levels are among the highest of any species examined at 32.2 and 28.4 percent for the two sites sampled. USDA's oil value (35.2 to 35.9 percent) places it among the top oil producers, but Georing,

Eslick and Brelsford's data (1965) show an oil level of 23.5 percent, placing it among the lowest of those species common to both research efforts.

Tumble Mustard's protein level (29.8 percent, Table IV-3) is higher than that of either cottonseeds or sunflower seeds (Table IV-5). Its carbohydrate level and T.D.N. (33.9 and 136.2 percent, respectively) are comparable or higher than these species, as well, when the higher oil level was used in the computation of T.D.N.

Plants were dry with no leaves when sampled, so biomass measurements were omitted. Shattering does not appear to be a problem. The seed may contain toxic glycosides common to the mustard family (Princen 1974; Hulbert and Oehme 1968), which often can be removed with careful processing.

Due to the high oil values observed for this species we give Tumble Mustard a high priority for further research.

Sisymbrium loeselii (Loesel Tumble Mustard) - The oil level for this species appears quite variable since the results for the three sampled sites are quite different from one another at 35.6, 27.9, and 17.7 percent. 6/ The higher oil levels are confirmed by Georing, Eslick, and Brelsford (1965) who reported an oil content of 30 percent for this species (Table IV-4).

This Mustard's protein levels are among the highest of any species examined at 31.3, 30.3 and 29.5 percent for the three sites sampled. Though the carbohydrate levels for the three sites show variability, the highest of these is above both cottonseeds' (46.6 percent) and soybeans' (33.7 percent) carbohydrate levels. S. loeselii's T.D.N. range from 118.6 to 141.5 percent. This range compares favorably for T.D.N. reported for cottonseed (127.0 percent), soybeans (118.6 percent), and sunflower seeds (131.3 percent).

S. loeselii has a severe shattering problem because pods on the same plant at the same instant will be shattered, mature, and unopened (green, maturing, and matured). Plants will often be flowering as well. Each plant produces many very small seeds that constituted only 7

6/ These results were each rechecked twice by Doty Laboratories, Inc.

percent for site 4 and 14 percent for site 17 of total plant weight (Table IV-9).

The seed meal of this species contains toxic mustard oil glycosides and, therefore, must be processed carefully (Princen 1979; Hulbert and Oehme 1968). For further information on these substances, see Brassica kaber.

Though this species oil level can be quite high, its severe shattering problem will make this species very difficult to cultivate. For this reason it was placed in the medium interest category rather than the high interest category.

Thlaspi arvense (Field Pennycress, Fanweed) - This species' oil level was in the mid range at 24 percent (Table IV-3), lower than USDA's 28.2-32.9 percent (Table IV-4), but close to Georing, Eslick, and Brelsford's (1965) 26.7 percent.

The protein level is 26.6 percent, higher than cottonseed or sunflower (Table IV-5). T. arvensis' carbohydrate level (43.7 percent) and T.D.N. (124.3 percent) also compare favorably.

Fanweed is small averaging only 1.9 grams (dry weight) per plant (Table IV-9); the seeds constitute 22 percent of the plant's dry weight, and contain allyl isothiocyanate, which in livestock causes gastric distress, bloody diarrhea, colic and, in extreme cases, paralysis of the heart and respiratory system (Stephens, 1980). This plant often causes difficulty in grazing cattle, but whether it is more toxic than other poisonous plants or whether it is so abundant that cattle eat more of it is not known. 7/

Fanweed's oil levels do not appear high enough to offset difficulties from the plant's small size and apparent toxicity, so it was given low priority for further investigations.

Xanthium strumarium (Cocklebur, Cow Cockle) - Our seed oil levels (10 percent, Table IV-3) are much lower than the USDA's at 35.7 to 38.2 percent (Table IV-4). The wide difference may have been caused by our

7/ Lloyd Hulbert 1982: personal communication.

samples containing the pericarp (the burr) while USDA samples did not. We included the pericarp because it was so difficult to separate from the seed, so, this species should be retained for further consideration.

The seeds and seedlings, however, contain hydroquinone, which can be quite toxic to livestock so death often occurs before symptoms can be diagnosed (Stephens 1980). (Only 400 to 500 seedlings will kill a 200 lb. pig.) The toxin is water soluble so it might be removed from seed meal by washing.

Though its oil and protein levels are potentially quite high, possible seed handling problems and toxicity of its seed placed this species in the medium priority grouping.

2. Potential Whole-plant-oil Plants

This section is organized into two subsections. The first examines overall plant analysis results and the second attempts a preliminary species grouping reflecting potential as whole-plant-oil plants. The latter section also contains a detailed discussion of each species considered in the sampling effort.

a. Overall results

Table IV-10 presents plant analysis results for the species examined in this study. Species highest in whole plant oil content are: Grindelia squarrosa (13.1, 10.7, and 10.0 percent for the three sites sampled) Solidago rigida (8.9, 8.3, and 8.1 percent for the three sites sampled) and Chrysothamnus nauseosus (8.7 and 8.0 percent for the two sites sampled). Those with lowest oil content are Carduus nutans (3.7, 2.2, and 1.7 percent for the three sites sampled), Agropyron repens (2.8 and 2.2 percent for the two sites sampled) and Argemone polyanthemos (1.9 percent).

Protein content ranges from 4.7 to 13.7 percent. Species with consistently high protein levels at all sampled sites are Kochia scoparia (12.9, 12.8, and 12.8 percent) and Asclepias speciosa (11.6, 10.9, and 10.5 percent). Those with consistently low protein content

Table IV-10. Plant analysis results for potential whole-plant-oil species. 1/

Family	Species	Common name	Site identification number	Percentages Oil	Protein (Nx6.25)	Carbohydrates 2/	T.O.N. 3/	Fiber	Ash
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	29	5.7	11.6	74.8	99.2	40.9	7.9
			39	6.1	10.5	70.9	95.1	24.7	12.5
			40	6.2	10.9	74.3	99.2	22.9	8.5
	A. syriaca	Common Milkweed	No sites located	-	-	-	-	-	-
	A. verticillata	Whorled Milkweed	No sites located	-	-	-	-	-	-
	A. viridiflora	Green Milkweed	No sites located	-	-	-	-	-	-
Asteraceae	Achillea millefolium	Yarrow	Plants not in collectable condition	-	-	-	-	-	-
	Artemisia campestris	Field Sagewort	32	6.9	5.7	82.6	103.8	38.8	4.7
			38	5.6	5.1	83.1	100.8	35.8	6.2
	A. ludoviciana	Cudweed Sagewort	34	3.8	4.7	87.0	100.3	40.1	4.5
			34	5.1	13.7	74.9	100.1	30.9	6.4
			40	2.6	-	-	-	-	-
	Carduus nutans	Musk Thistle	17	1.7	-	-	-	-	-
			26	3.7	9.0	75.6	92.8	36.2	11.7
			27	2.2	-	-	-	-	-
	Chrysothamnus nauseosus	Rubber Rabbitbrush	30	8.7	8.7	77.7	106.0	30.0	4.9
			31	8.0	8.1	79.6	105.7	35.1	4.4
	C. viscidiflorus	Green Rabbitbrush	No sites located	-	-	-	-	-	-
	Cirsium arvense	Canada Thistle	2	2.5	-	-	-	-	-
			10	4.6	8.7	76.9	96.0	31.6	9.8
			28	3.4	8.8	75.6	92.1	32.9	12.2
	C. undulatum	Wavyleaf Thistle	32	5.5	7.4	79.2	98.9	34.5	7.9
	Grindelia squarrosa	Curly-cup Gumweed	32	13.1	8.2	68.6	106.3	27.1	10.1
			33	10.0	7.6	73.5	103.6	34.6	8.9
			38	10.7	12.5	67.5	104.1	31.8	9.3
	Gutierrezia sarothrae	Broom Snakeweed	28	7.8	7.3	66.6	91.5	22.0	18.3
			35	6.4	6.6	68.2	88.3	25.2	18.9
			41	7.6	10.6	64.9	92.6	25.2	16.9

Continued....

Table IV-10. (Continued)

Family	Species	Common name	Site identification number	Percentages: Oil	Protein (Nx6.25)	Carbohydrates 2/	T.D.N. 3/	Fiber	Ash
	Liatris punctata	Dotted Blazingstar	35	5.3	6.2	80.0	98.0	36.0	8.5
			36	5.2	6.4	80.0	98.1	35.9	8.4
	Solidago rigida	Stiff Goldenrod	34	8.3	5.4	80.2	104.3	30.3	6.1
			35	8.1	6.5	79.1	103.8	29.5	6.4
			36	8.9	5.7	78.6	104.3	27.1	6.7
	Tragopogon dubius	Common Salsify	30	5.0	5.3	80.5	97.1	30.3	9.3
			33	5.2	5.4	79.6	96.7	39.7	9.8
Caprifoliaceae	Symphoricarpos orbiculatus	Coralberry	No sites located	-	-	-	-	-	-
Chenopodiaceae	Chenopodium album	Lambsquarter, White Goosefoot	Seeds already dispersed	-	-	-	-	-	-
	Kochia scoparia	Kochia, Summer Cypress	4	3.1	12.9	72.9	92.8	28.6	11.1
			38	3.8	12.8	73.3	94.7	28.5	10.0
			39	2.7	12.8	74.2	93.1	32.8	10.3
	Salsola kali	Russian Thistle	39	5.3	10.8	67.6	90.3	27.4	16.4
			41	4.7	6.9	73.8	91.3	31.7	14.9
Euphorbiaceae	Euphorbia esula	Leafy Spurge	2	4.9	7.6	78.3	96.9	37.3	9.2
	E. marginata	Snow-on-the-Mountain	24	4.7	9.7	72.7	93.0	29.8	12.9
	E. spathulata	Spatula-leaved Spurge	No sites located	-	-	-	-	-	-
Gramineae	Agropyron repens	Quack Grass	27	2.2	-	-	-	-	-
			28	2.8	-	-	-	-	-
	Elymus canadensis	Canada Wildrye	Seeds already dispersed	-	-	-	-	-	-
Papaveraceae	Argemone polyanthemos	Prickly Poppy	19	1.9	-	-	-	-	-

1/ All data are calculated on a dry weight bases. When oil content was below 3 percent, no other tests were run.

2/ Includes fiber and nitrogen-free extract.

3/ T.D.N. - total digestible nutrients. We assumed no digestibility coefficients in calculating T.D.N. (i.e., T.D.N. = 2.25 x oil (%) + carbohydrates (%) + protein (%)). Thus, this T.D.N. expresses the total potential nutrients available in the seed. See text page 56 for further explanation.

Source: Development Planning and Research Associates, Inc.

are Artemisia campestris (5.7 and 5.1 percent), Tragopogon dubius (5.4 and 5.3 percent), and Solidago rigida (6.5, 5.7, and 5.4 percent). One species, Artemisia ludoviciana, shows great variability in its protein content with levels of 13.7 and 4.7 percent for the two sampled sites.

Table IV-11 shows forage analysis data for plants (alfalfa, barley, brome, oats, and wheatgrass) commonly used in Montana as feedstuffs. The protein content for these plants range from 4.1 to 17.0 percent. Many of the species examined as whole-plant-oil plants have protein levels in the central portion of this range. None fall below it. The carbohydrate levels and T.D.N. for these species compare favorably with levels of common Montana feedstuffs plants as well. Of those species with plant oil content above 3 percent 8/, only Grindelia squarrosa, Gutierrezia sarothrae and Salsola kali have carbohydrate levels falling well below the examined Montana feedstuffs' carbohydrate range (71 to 87 percent). Only the T.D.N.'s of Gutierrezia sarothrae and Salsola kali fall consistently below the examined Montana feedstuffs' T.D.N. range (93 to 98 percent).

Because plants may be poisonous to animals, both toxicity information and field observations are given in Table IV-12. Most of the species contained some toxin and several seemed to have agronomic difficulties.

b. Preliminary species grouping

Species examined as potential whole-plant-oil plants were placed in priority groupings to aid the Montana DNRC direct further research on these species. The initial ranking by oil content, shown in Table IV-13, was based on the following grouping:

Initial priority grouping	Oil level, %
High	>6
Medium	>3, but ≤6
Low	≤3

8/ We did no additional seed analyses on species with lower oil levels.

Table IV-11. Forage analysis data for plants often used in Montana as feedstuffs

Plant	Oil	Protein	Carbohydrates 1/	T.D.N. 2/	Fiber	Ash
Alfalfa 3/ (hay)	1.9	17.0	71.2	92.5	30.6	9.9
Barley 3/ (straw)	1.9	4.1	87.0	95.4	41.6	6.9
Brome 3/ (Bromegrass hay)	2.4	11.7	76.7	93.8	31.8	9.2
Oats 3/ (hay)	2.1	8.5	81.2	94.4	30.8	8.2
Wheatgrass, crested 4/ (hay, cut early)	2.2	10.2	80.5	95.7	35.8	7.1

1/ Includes fiber and nitrogen free extract.

2/ T.D.N. = total digestible nutrients. We assumed no digestibility coefficients in calculations (i.e., T.D.N. = 2.25 x oil (%) + carbohydrates (%) + protein (%)). Thus, the T.D.N. expresses the total potential nutrients available in the seed. See text page 56 for further explanation.

3/ Source: A. E. Cullison, Feeds and Feeding, (Reston, Va.: Reston Publishing Company, Inc., 1982).

4/ Source: F. B. Morrison, Feeds and Feeding, (Clinton, Iowa: The Morrison Publishing Company, Inc., 1959).

Table IV-12. Potential agronomic and toxicity problems of species considered as whole-plant-oil plants

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
Asclepiadaceae	Asclepias speciosa	Showy Milkweed	Moisture requirements may restrict production area	Resinoids, Glycosides	All parts	More toxic than mustards that contain similar toxins; toxin can be removed with methanol; livestock find plants unpalatable.
	A. syriaca	Common Milkweed	--	Resinoids, Glycosides	All parts	More toxic than mustards that contain similar toxins; toxin can be removed with methanol; livestock find plants unpalatable.
	A. verticillata	Whorled Milkweed	Plants are small, 3-6 dm tall	Resinoids, Glycosides	All parts	More toxic than mustards that contain similar toxins; toxin can be removed with methanol; livestock find plants unpalatable.
	A. viridiflora	Green Milkweed	Plants are small, 2-5 dm tall	Resinoids, Glycosides	All parts	More toxic than mustards that contain similar toxins; toxin can be removed with methanol; livestock find plants unpalatable.
Asteraceae	Achillea millefolium	Yarrow	Plants are small, 3-5 dm tall	--	--	Ingestion of plant can taint milk products.
	Artemisia campestris	Field Sagewort	May be too short on driest sites (< 4 dm tall)	--	--	--
	A. ludoviciana	Cudweed Sagewort	May be too short on driest sites (< 4 dm tall)	--	--	--
	Carduus nutans	Musk Thistle	--	Nitrates	Leaves	Not as toxic as some other toxins and animals can tolerate some nitrates in diet. Care must be taken because not all possible dietary sources are always known and stress can affect animal's tolerance. Washing with water may reduce levels. Spines may injure feeding animal if feed is not processed carefully.

Continued...

Table IV-12. (Continued)

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
	Chrysothamnus nauseosus	Rubber Rabbitbrush	--	--	--	--
	C.viscidiflorus	Green Rabbitbrush	--	--	--	--
	Cirsium arvense	Canada Thistle	Noxious weed; could be difficult to eradicate after cultivated because reproduces by rhizomes	Nitrates	Leaves	Not as toxic as some other toxins and animals can tolerate some nitrates in diet. Care must be taken because not all possible dietary sources are always known and stress can affect animal's tolerance. Washing with water may reduce levels. Spines may injure feeding animal if feed is not processed carefully.
	C. undulatum	Wavyleaf Thistle	--	--	--	Spines may injure feeding animal if feed is not processed carefully.
	Grindelia squarrosa	Curly-cup Gumweed	Plants are small, 3-6 dm tall, but often 5 dm tall	Selenium	Leaves	Only a problem in areas where soil selenium levels are high. Difficult to extract once in plant.
	Gutierrezia sarothrae	Broom Snakeweed	Plants are small, 3-6 dm tall, but often 3 dm tall	Selenium	All parts	Only a problem in areas where soil selenium levels are high. Difficult to extract once in plant.
	Liatris punctata	Dotted Blazingstar	Plants are small, 1-7 dm tall, but often 4 dm tall	--	--	--
	Solidago rigida	Stiff Goldenrod	May be too short on drier sites	Resinoids	Leaves at flowering time	--
	Tragopogon dubius	Common Salsify	--	--	--	--
Caprifoliaceae	Symphoricarpos orbiculatus	Coralberry	--	--	--	--

Continued....

Table IV-12. (Continued)

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
Chenopodiaceae	*Chenopodium album*	Lambsquarter, White Goosefoot	--	Oxalates 3/ Nitrates	Leaves, seeds, vegetative tissue	Can be quite toxic, but animals tolerate low levels of this toxin in diet. Levels may be reduced by water washing.
	Kochia scoparia	Kochia, Summer Cypress	--	Oxalates 3/	Leaves, seeds	Can be quite toxic, but animals tolerate low levels of this toxin in diet. Levels may be reduced by water washing.
				Nitrates	Vegetative tissue	Not as toxic as some other toxins and animals can tolerate some nitrates in diet. Care must be taken because not all possible dietary sources are always known and stress can affect animal's tolerance. Washing with water may reduce levels
				Photosensitizer	Leaves	--
				Saponins	Seeds	May be extracted with hexane or alcohol.
	Salsola kali	Russian Thistle	--	Oxalates 3/	Leaves, seeds	Can be quite toxic, but animals tolerate low levels of this toxin in diet. Levels may be reduced by water washing.
Euphorbiaceae	*Euphorbia esula*	Leafy Spurge	Noxious weed; may be hard to eradicate after cultivation because reproduces by by rhizomes and birds readily disperse seeds.	Acrid principle	All parts	Acrid principle toxin is characteristic of this genus. Toxicity varies by species. *E. esula* does not appear to be as toxic as some other *Euphorbias* since there are reports of it being successfully fed to sheep.

Continued....

Table IV-12. (Continued)

Family	Species	Common name	Apparent agronomic 1/ difficulties	Toxicity problems 2/		
				Toxin	Plant parts affected	Comments
	E. marginata	Snow-on-the-Mountain	--	Acrid principle	All parts	All parts are poisonous to some extent. The milky juice may cause dermatitis with blisters. The acrid toxin is not destroyed by drying. Livestock find plant unpalatable.
	E. spathulata	Spatula-leaved Spurge	--	Acrid principle	All parts	All parts are poisonous to some extent. The milky juice may cause dermatitis with blisters. The acrid toxin is not destroyed by drying. Livestock find plant unpalatable.
Gramineae	Agropyron repens	Quack Grass	May be hard to eradicate after cultivation because it reproduces by rhizomes.	--	--	--
	Elymus canadensis	Canada Wildrye	--	--	--	--
Papaveraceae	Argemone polyanthemos	Prickly Poppy	--	Alkaloids	All parts	This group of toxins is associated with the Poppy family. This species may or may not contain them in levels toxic to livestock.

1/ From file observations of DPRA research team. Agronomic problems (e.g., germination, allelopathy) other than those given may exist for the listed species; however, none was readily apparent from field observation.

2/ From: Plant Resources Institute, A Large Scale Demonstration of Fuel/Chemical Feedstock Production from Showy Milkweed (Asclepias speciosa), U.S. Department of Energy, Division of Distributed Solar Technology, San Francisco, California, 1982; H. D. Fuehring, "Kochia as a Forage Crop," unpublished paper from New Mexico State University Plains Branch Station, Clovis, N. M., 1982; H. A. Stephens, Poisonous Plants of the Central United States, (Lawrence, Kans.: The Regents Press of Kansas, 1980); G. D. Buck, G. A. Osweiler and G. A. Gelder, Clinical and Diagnostic Veterinary Toxicology, (Dubuque, Iowa: Kendall/Hunt Publishing Company, 1973); E. C. M. Coxworth, J. M. Bell and R. Ashford, "Preliminary Evaluation of Russian Thistle, Kochia and Garden Atriplex as Potential High Protein Seed Crops for Semiarid Areas, Canadian Journal of Plant Science 49(1968):422-434; L. D. Hulbert and F. W. Oehme, Plants Poisonous to Livestock, (Manhattan, Kansas: Kansas State University, 1968); W. F. Booth and J. C. Wright, 1966. Flora of Montana, (Bozeman, Montana: Montana State University, 1966); W. C. Muenscher, Poisonous Plants of the United States, (New York: Macmillan Company, 1948); conversations with veterinary toxicologist, animal scientist, and agronomist at Kansas State University (1982).

3/ Ruminants are less susceptible to oxalate because most of it is metabolized in the rumen. Ruminants can eat much more oxalate-containing plants without being affected than nonruminants can.

Table IV-13. Ranking of sampled species by oil content 1/

Species	Common name	Oil	Initial priority grouping
		(%)	
Grindelia squarrosa	Curly-cup Gumweed	13.1	High
Solidago rigida	Stiff Goldenrod	8.9	High
Chrysothamnus nauseosus	Rubber Rabbitbrush	8.7	High
Gutierrezia sarothrae	Broom Snakeweed	7.8	High
Artemisia campestris	Field Sagewort	6.9	High
Asclepias speciosa	Showy Milkweed	6.2	High
Cirsium undulatum	Wavyleaf Thistle	5.5	Medium
Liatris punctata	Dotted Blazingstar	5.3	Medium
Salsola kali	Russian Thistle	5.3	Medium
Tragopogon dubius	Common Salsify	5.2	Medium
Artemisia ludoviciana	Cudweed Sagewort	5.1	Medium
Euphorbia esula	Leafy Spurge	4.9	Medium
Euphorbia marginata	Snow-on-the-Mountain	4.7	Medium
Cirsium arvense	Canada Thistle	4.6	Medium
Kochia scoparia	Kochia, Summer Cypress	3.8	Medium
Carduus nutans	Musk Thistle	3.7	Medium
Agropyron repens	Quack Grass	2.8	Low
Argemone polyanthemos	Prickly Poppy	1.9	Low

1/ Note the highest oil content found for each species was used to rank the species.

Source: Development Planning and Research Associates, Inc.

After the initial priority grouping, we felt undesirable agronomic characteristics reduced a species' grouping by ½ to 1 level depending on its severity. Agronomic characteristics considered included small plant size (i.e., possible low yields) moisture requirements restricting where plants may be cultivated, and whether a species would be hard to eradicate from a field once it is cultivated. Unfavorable toxicity characteristics included potentially high toxicity and difficulty in removing toxin from plant meal. Whole plant nutrient levels (i.e., protein, T.D.N. and carbohydrates) though considered, did not affect priority grouping greatly because most sampled species with more than 3 percent plant oil had nutritional levels within the same range of plants commonly used in Montana as feedstuffs.

Not enough comparable secondary data exist to include in the priority grouping those species with possible potential we were unable to sample. These species are: Asclepias syriaca, A. verticillata, A. viridiflora, Achillea millefolium, Chrysothamnus viscidiflorus, Symphoricarpos orbiculatus, Chenopodium album, Euphorbia spathulata, and Elymus canadensis. Theses were not sampled because either they are uncommon and hard to find or they were not in the proper phenological state. Uncommon species should not be eliminated from further consideration because we could not find them. Their uncommonness does not necessarily mean that they would not do well in Montana. Both competition and seed dispersal characteristics could keep plant abundance down or absent, but agricultural situations can be altered to enhance a plant's growth and reproduction. Of particular interest among the unsampled species are the three milkweed species (Asclepias syriaca, A. verticillata, A. viridiflora) and Chrysothamnus viscidiflorus since they are closely related to sampled species (Asclepias speciosa and Chrysothamnus nauseosus) with high plant oil levels.

Table IV-14 presents the preliminary priority grouping. The only species in the highest priority grouping is Chrysothamnus nauseosus. Those in the next highest grouping are Artemisia campestris, Asclepias speciosa, Grindelia squarrosa, and Solidago rigida. Species of lowest interest are Agropyron repens, Argemone polyanthemos, Cirsium arvense, Euphorbia esula, and Kochia scoparia.

Table IV-14. Preliminary priority grouping of native and naturalized species considered as potential whole-plant-oil plants

Priority grouping	Species	Common name	Comments
High interest	Chrysothamnus nauseosus	Rubber Rabbitbrush	Oil content is high. No apparent toxicity and agronomic problems. Plants respond well to multiple clippings.
Medium to high interest	Artemisia campestris	Field Sagewort	Oil content is in the lower portion of the high range. Plants may be short on the driest sites.
Medium to high interest	Asclepias speciosa	Showy Milkweed	Oil content is in the lower portion of the high range. Moisture requirements may restrict production area.
Medium to high interest	Grindelia squarrosa	Curly-cup Gumweed	Oil content is extremely high, but small stature may make yields inadequate. Plants tend to accumulate selenium when it is present in the soil.
Medium to high interest	Solidago rigida	Stiff Goldenrod	Oil content is high, but plants may be too short on drier sites to provide adequate yields without irrigation. Toxicity at flowering time should be examined.
Medium interest	Cirsium undulatum	Wavyleaf Thistle	Oil content is in mid range of species examined. Feed quality appears good though care must be taken in processing because plants have spines.
Medium interest	Euphorbia marginata	Snow-on-the-Mountain	Oil levels are in the mid range of species studied. Toxicity should be examined carefully.
Medium interest	Gutierrezia sarothrae	Broom Snakeweed	Though oil levels are high, plants are small and yields may not be adequate. Plants accumulate selenium when it is present in soil. Feed nutritional levels are not as high as other species examined.
Medium interest	Salsola kali	Russian Thistle	Oil content is in the medium range of species sampled. Feed nutritional levels are not as high as other species examined. Potential toxicity problems should be investigated carefully.
Medium interest	Tragopogon dubius	Common Salsify	Oil content is in the medium range of species examined. Protein levels are low. No known toxicity and agronomic problems.
Low to medium interest	Artemisia ludoviciana	Cudweed Sagewort	Oil content is in the medium range of species sampled. Plants may be short on driest sites.
Low to medium interest	Carduus nutans	Musk Thistle	Oil content is in the low to medium range. Due to nitrates in plant meal, care must be taken when feeding to animals. Feed must be processed carefully because plants have spines.
Low to medium interest	Liatris punctata	Dotted Blazingstar	Though oil content is in the mid range of species examined, plants tend to be small and yields may be inadequate.

Continued....

Table IV-14. (Continued)

Priority grouping	Species	Common name	Comments
Low interest	Agropyron repens	Quack Grass	Low oil levels and problems eradicating after cultivation give this species low priority for further study.
Low interest	Argemone polyanthemos	Prickly Poppy	Oil content was the lowest of any species examined. Plant meal may have toxicity problems.
Low interest	Cirsium arvense	Canada Thistle	Oil levels are not high enough to balance potential eradication and toxicity problems.
Low interest	Euphorbia esula	Leafy Spurge	Oil content is in mid range of species examined, but potential eradication problems make this plant of low interest.
Low interest	Kochia scoparia	Kochia, Summer Cypress	Oil content is in the low to medium range. Plants have potential allelopathy and toxicity problems.

Source: Development Planning and Research Associates, Inc.

Sampling results, agronomic problems, toxicity, and other factors considered in the priority grouping follow, with species arranged in alphabetical order.

Agropyron repens (Quack Grass) - This species' oil levels, 2.2 and 2.8 percent for the two sampled sites, are among the lowest of any species tested. No other analyses were performed because the oil level was below the 3 percent cutoff. This plant does not appear to have any presently known toxicity problems. 9/ There may be agronomic difficulties because the plant reproduces by rhizomes, making plants hard to eradicate after cultivation.

Because of low oil levels and possible agronomic problems this species should be given a low priority for further study.

Argemone polyanthemos (Prickly Poppy) - The plant oil content (1.9 percent) for this species is the lowest of any species examined. Members of the Poppy family often contain alkaloids that may be toxic if the plant meal is fed to livestock (Stephens 1980). For these reasons, Prickly Poppy should be given a very low priority for further study.

Artemisia campestris (Field Sagewort) - Plant oil levels for this species are 6.9 and 5.6 percent for the two sites sampled. The higher of these oil levels places Field Sagewort in the highest initial priority grouping (see Table IV-13). Protein content (5.7 and 5.1 percent) is among the lowest of any species examined though it is in the range of the Montana feedstuffs examined (Table IV-11). Carbohydrate levels (82.6 and 83.1 percent) and T.D.N. (103.8 and 100.8 percent) are among the highest and are comparable with those of common Montana feedstuffs (Table IV-11).

There are no presently known toxins for this species. 9/ Plants may be short on driest sites resulting in inadequate yields. For this

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9/ Much of what is known about plants poisonous to livestock has come from observations on range grazing. A species not known as poisonous could be poisonous but avoided by livestock. So large amounts should not be fed to animals until the seeds have been tested.

reason and because oil content is just above the 6 percent cutoff level for the highest initial priority grouping, A. campestris was placed in the "medium to high interest" priority grouping.

Artemisia ludoviciana (Cudweed Sagewort) - This species' oil levels for the three sites sampled are 5.1, 3.8, and 2.6 percent, placing A. ludoviciana in the mid-range of species examined. Protein levels are variable, 4.7 and 13.7 percent for the two samples analyzed for feed quality. These are both in the range of protein levels found in common Montana feedstuffs (Table IV-11). This species' carbohydrate levels (74.9 and 87.0 percent) and T.D.N. (100.1 and 100.3 percent) are also in the range of levels found for common Montana feedstuffs (See Table IV-11).

There do not appear to be any presently known toxins for this species (Table IV-12). Though plants may be small in driest sites, this species should be considered further as a whole-plant-oil species.

Asclepias speciosa (Showy Milkweed) - Oil content levels are 5.7, 6.1, and 6.2 percent for the three sampled sites placing this species in the middle to high oil content range for those species examined. Protein levels are 10.5, 10.9, and 11.6 percent for the three sampled sites. These are among the highest for any species sampled and they are higher than barley straw (4.1 percent), oat hay (8.5 percent), bromegrass hay (11.7 percent), or crested wheatgrass (10.2 percent). Carbohydrate levels (70.9, 74.3, and 74.8 percent) are in the lower range of levels for common Montana feedstuffs (see Table IV-11). Showy Milkweed's T.D.N. levels (99.2, 95.1, and 99.2 percent) are comparable to or higher than the T.D.N. levels for these feedstuffs (see Table IV-11).

All members of the Asclepias genus contain resinoids and glycosides which can be more toxic than those found in mustards. 10/ Sheep are primarily affected, but cases have been reported in horses and cattle (Hulbert and Oehme, 1968). These toxins can cause high body temperatures, difficulty in standing and walking, spasms and coma. Death may result because of respiratory failure. According to recent

10/ Frederick Oehme 1982: personal communication.

research by the Plant Resources Institute (1982), Asclepias speciosa tends to be less toxic than other members of this genus because of low levels of these toxic compounds. Research at this institute has also shown that these toxins are reasonably soluble in methanol and can be extracted using this substance.

Showy Milkweed's moisture requirements may restrict its production area in Montana. For this reason and because this plant's oil content is in the middle to high range, A. speciosa was placed in the middle to high interest priority grouping.

Carduus nutans (Musk Thistle) - This species' oil content is in the low to mid range for those species sampled. Levels for the three sampled sites are 3.7, 2.2, and 1.7 percent. Protein content for the one sample on which further analyses were run was 9.0 percent. This level is above both barley straw (4.1 percent) and oat hay (8.5 percent). Both carbohydrate level (75.6 percent) and T.D.N. (92.8 percent) are within the range of common Montana feedstuffs (See Table IV-11).

Musk Thistles tend to accumulate nitrates in their leaves. Though animals can tolerate a certain amount of nitrates in their diet, care must be taken because not all dietary sources are always known and stress can affect an animal's tolerance. Nitrates can be removed with water washing. Another potential feed difficulty results because Musk Thistles are covered with spines which can injure the mouths of feeding animals if the plant meal is not processed carefully.

Because of its low to medium oil levels, this species was placed in the low to medium interest priority grouping.

Chrysothamnus nauseosus (Rubber Rabbitbrush) - This species' oil content is among the highest of any species examined at 8.7 and 8.0 percent for the two sites sampled. Protein content levels are 8.7 and 8.1 percent which is above barley straw (4.1 percent) and in the same range as oat hay (8.5 percent). Carbohydrate levels (77.7 and 79.6 percent) are in the lower range of common Montana feedstuffs (see Table IV-11). Its T.D.N. levels (105.7 and 106.0 percent) are well above T.D.N. levels for these feedstuffs, as well.

There are no currently known toxins for this species. Based on field observations, there are no apparent agronomic difficulties as. Research by Heese Products Company indicates that Rubber Rabbitbrush plants respond well to multiple clippings during the growing season. 11/ Given this species' high oil content and favorable feed and agronomic characteristics, C. nauseosus should be given a very high priority for further study.

Cirsium arvense (Canada Thistle) - This species' oil levels are 4.6, 3.4, and 2.5 percent for the three sites sampled. Protein levels are 8.8 and 8.7 percent which are above barley straw's (4.1 percent) and close to that of oat hay (8.5 percent). Canada Thistle's carbohydrate levels (76.9 and 75.6 percent) are in the lower range of levels for common Montana feedstuffs (see Table IV-11). Its T.D.N. levels (96.0 and 92.1 percent) are comparable to T.D.N. levels for these feedstuffs.

C. arvense can accumulate nitrate in its leaves. Animals can tolerate some nitrates in their diet, but at higher levels illness and even death can result. Care must always be taken when feeding nitrate containing substances to livestock since not all diet sources are always known and stress can affect an animal's tolerance. Nitrates can be removed by water washing. Plants are covered with spines which can injure the mouths of feeding animals if the plant meal is not processed carefully.

C. arvense is classified as a noxious weed by the State of Montana, making it illegal to allow plants to go to seed. Consequently, Montana law would have to be changed to allow cultivation. This species will be difficult to eradicate after cultivation because plants reproduce by rhizomes.

C. arvense's oil level is not high enough to balance potential weed and toxicity problems. Consequently, this species should be given a low priority for further research.

11/ Darrell Lemare 1982: personal communication.

Cirsium undulatum (Wavyleaf Thistle) - This species' oil content (5.5 percent) is in the mid range of species sampled. Protein content (7.4 percent) is among the lowest of species sampled; however, this level is above barley straw's protein content (4.1 percent). C. undulatum's carbohydrate level (79.2 percent) and T.D.N. (98.9 percent) are well within the range of levels shown in Table IV-11 for common Montana feedstuffs. Spines are present on plants, and care must be taken in feed processing to assure feeding animals are not injured.

Due to this plants oil levels C. undulatum should be considered further for study.

Euphorbia esula (Leafy Spurge) - This species' oil content (4.9 percent) is in the mid range of species examined. Its protein content is 7.6 percent which is just below the mid range of protein levels for common Montana feedstuffs (Table IV-11). Leafy Spurge's carbohydrate levels (78.3 percent) and T.D.N. (96.9 percent) are in the mid range of levels for these feedstuffs.

Members of the Euphorbia genus contain an acrid toxin that severely irritates the mouth, throat and stomach (Stephens 1980; Oehme and Hulbert 1968). Studies, however, have shown that sheep tolerate and may even show a preference for Leafy Spurge indicating that this species may not be as toxic as some of the other members of this genus. (Christensen et al. 1938; Helgeson and Thompson 1939; Johnston and Peake 1960; Landgraf, Fay and Havstad 1982.)

E. esula is classified by the State of Montana as a noxious weed making it illegal to allow plants to go to seed. Consequently, Montana law could have to be changed to allow cultivation. Plants may be difficult to eradicate from fields once the are cultivated because they reproduce by rhizomes. Seeds are also readily dispersed by birds.

Though Leafy Spurge's oil content is in the mid range of species examined, its potential eradication problems and its current status under Montana law make of low interest for further study.

Euphorbia marginata (Snow-on-the-Mountain) - This species' oil level (4.7 percent) is in the mid range of the species examined. Its protein

content is 9.7 percent, which is higher than the protein content of both barley straw (4.1 percent) and oat hay (8.5 percent). E. marginata's carbohydrate level (72.7 percent) and T.D.N. (93.0 percent) are comparable to those of alfalfa (71.2 and 92.5 percent respectively).

Members of Euphorbia often contain an acrid toxin that can severely irritate the mouth, throat, and stomach. Livestock also find these species unpalatable. (Stephens 1980; Oehme and Hulbert 1968). Despite this, E. marginata's oil levels are high enough to warrant further study.

Grindelia squarrosa (Curly-cup Gumweed) - The oil content for this species was the highest of any species examined at 13.1, 10.7, and 10.0 percent at the three sites sampled. Protein levels are variable among the three sites at 12.5, 8.2, and 7.6 percent. The highest of these is above reported levels for barley straw, oat hay, crested wheatgrass, and bromegrass hay. Though this Gumweed's T.D.N. (106.3, 104.1, and 103.6 percent) is well above the T.D.N. for these species, its carbohydrate content (73.5, 68.6, and 67.5 percent) is lower.

G. squarrosa plants tend to accumulate selenium. This is a problem only areas where soil selenium is high. The average selenium level in forages is used as an indication of areas high in selenium. In that portion of Montana east of the Rocky Mountains a high selinium level (.26 ppm-average) in forages is common, indicating that G. squarrosa plants grown in this area might produce meal which contains toxic levels of this substance. Unfortunately, selenium cannot be removed through processing. Forages grown in the Golden Triangle have much lower average selenium levels (.05 ppm); therefore, G. squarrosa grown in this area will be less likely to have a toxicity problem. (Buck, Osweiler and Gelder 1973).

Plants of this species tend to be small ranging from 3 to 6 dm tall. Consequently, yield levels may not be adequate. This characteristic may be difficult to alter since plant size is hard to change through plant breeding unless the genetic variability is available to do so. Consequently, though oil levels are extremely high, this species was placed in the medium to high interest priority category.

Gutierrezia sarothrae (Broom Snakeweed) - This plant's oil levels are high at 7.8, 7.6, and 6.4 percent for the three sites sampled. Protein levels are 10.6, 7.3, and 6.6 percent; these are in the mid range for common Montana feedstuffs (see Table IV-11). Broom Snakeweed's carbohydrate levels (68.2, 66.6, and 64.9 percent) and T.D.N. (92.6, 91.5, and 88.5 percent) tend to be lower than those for Montana feedstuffs (Table IV-11).

Broom Snakeweed plants tend to collect selenium. This is a problem only where soil selenium levels are high. This substance is difficult to extract from plant meal.

G. sarothrae plants tend to be short, growing only 3 to 6 dm tall. Most plants we observed in the field were only 3 dm tall. Yields may not be adequate from such small plants. This characteristic may be difficult to alter since plant size is hard to change through plant breeding unless the genetic variability is available to do so. Consequently, though Broom Snakeweed's oil content appears high, it was given a medium priority for further research.

Kochia scoparia (Kochia, Summer Cypress) - This species' oil content is in the low to medium range for those species examined, at 3.8, 3.1, and 2.7 percent for those sites sampled. Protein levels are among the highest of any sampled species, 12.9, 12.8, and 12.8 percent. These levels are higher than the protein content of all common Montana feedstuffs shown in Table IV-11 except for alfalfa (17.0 percent). Kochia's carbohydrate levels (74.2, 73.3, and 72.9 percent) are in the lower range for these feedstuffs and its T.D.N. (94.7, 93.1, and 92.8 percent) in the low to mid range.

Kochia contains several toxins (oxalates, nitrates, and saponins) and a photosensitizer. Oxalates and nitrates can be tolerated in an animal's diet 12/; however, care must be taken to assure livestock are not eating too much of these substances. In the case of nitrates, not all dietary sources are always known and stress can affect an animal's

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12/ This is more true of ruminants than nonrummants because oxalate is metabolized in the rumen.

tolerance. Oxalate and nitrate feed meal levels can be reduced through water washing. The saponins found in Kochia's seeds can be extracted using hexane (Coxworth, Bell, and Ashford 1968).

Kochia may have allelopathic effects on the immediately succeeding crop. Fuehring (1982) reported that wheat or grain sorghum under limited irrigation after Kochia had very restricted root growth and yielded only one-third their normal levels in 1980. He stated that leaving a field fallow one year would likely eliminate that problem, since in 1981, a wet year, no such effect was apparent.

This species' low to medium oil levels combined with its potential allelopathy and toxicity problems give it a low priority for further research.

Liatris punctata (Dotted Blazingstar) - This species oil content is in the medium range of examined species at 5.3 and 5.2 for the two sampled sites. Protein contents at the two sites are 6.2 and 6.4 percent, respectively. These levels are in the lower range of common Montana feedstuffs (see Table IV-11). Dotted Blazingstar's carbohydrate levels (80 percent at both sites) are in the middle range for these feedstuffs; its T.D.N. levels (98.0 and 98.1 percent) are above the T.D.N.'s for these feedstuffs.

L. punctata plants can be small with height ranging from 1 to 7 dm (Booth and Wright 1966). Most plants observed in the field were 4 dm tall. For this reason, L. punctata was placed in the low to medium interest grouping rather than the medium interest grouping indicated by its oil content.

Salsola kali (Russian Thistle) - This species' oil contents for the two sampling sites are in the mid range for the species sampled at 5.3 and 4.7 percent. Protein levels are somewhat different between the two sites - 10.8 and 6.9 percent. These levels are in the low to mid range for the Montana feedstuffs shown in Table IV-11. Carbohydrate levels are also variable at 73.8 and 67.6 percent. The higher is in low range for the Montana feedstuffs shown in Table IV-11, and lower is below this range. Russian Thistle's T.D.N.s (91.3 and 90.3 percent) are below the range for these feedstuffs.

Russian Thistles leaves and seeds can contain oxalates. Though these can be quite toxic, animals (especially ruminants) can tolerate low levels in their diet. Levels can be reduced by water washing feed meal. In spite of this toxin, this plant's oil levels are high enough for it to be examined further.

Solidago rigida (Stiff Goldenrod) - Oil contents for the three sampled sites are 8.9, 8.3, and 8.1 percent placing this species in the high range of species sampled. Protein levels tend to be lower than many of the other species sampled at 6.5, 5.7, and 5.4 percent. This is in the lower portion of the range for common Montana feedstuffs (see Table IV-11). Both carbohydrate levels (80.2, 79.1, and 78.6 percent) and T.D.N. levels (104.3, 104.3, and 103.8 percent) compare favorably with these feedstuffs.

Resinoids found in the leaves near flowering time can be toxic to livestock. Plants tend to be short on drier sites. Consequently, in spite of this plants high oil levels, it was placed in the medium to high interest category.

Tragopogon dubius (Common Salsify) - Oil levels (5.2 and 5.0 percent) are in the mid range of species sampled. Protein levels are low at 5.3 and 5.4 percent; however, these are higher than barley straw's (4.1 percent). Common Salsify's carbohydrate levels (80.5 and 79.6 percent) and T.D.N. levels (97.1 and 96.7 percent) compare favorably with common Montana feedstuffs (see Table IV-11). There are no known toxins for this species. 13/ This plant should be considered further as a potential whole-plant-oil species.

13/ Much of what is known about plants poisonous to livestock has come from observations on range grazing. A species not known as poisonous could be poisonous but avoided by livestock. So large amounts should not be fed to animals until the seeds have been tested.

V. ADAPTABLE OIL-BEARING PLANTS

This chapter examines promising oil-bearing plants not native to Montana and assesses each's ability to be grown there. The information is presented in two parts. First, species that have become well known because of their potential to produce oil are reviewed and assessed. Second, the work of Georing, Eslick, and Brelsford (1965) is examined as they grew several nonnative Cruicferae in Montana and evaluated each's ability to produce oil high in erucic acid.

A. Promising Oil-bearing Plants

The USDA Northern Regional Laboratory in Peoria, Illinois likely has performed the most extensive screening of species (more than 8,000 from the U.S. and around the world), for potential oil-producing plants. Princen (1979) reviewed the species with the most potential. Another article (Morgan and Shultz, 1981) discusses species which have been isolated for their promise for fuel and chemical production. The species discussed in those articles are examined here relative to their potential as oil-bearing plants and their near-term adaptability to Montana. Following the species discussions is a brief summary of the species that likely have the greatest potential in Montana.

Brassica napus and *B. campestris* (Rapeseed) - Though the oil from cultivated varieties of these species is used primarily in food, breeding programs are now underway to develop a low glucosinolate, high erucic acid rapeseed for the production of industrial oil. Several seed lines have been obtained with 40 percent oil, of which 55 percent is erucic acid, and 1 percent glucosinolate (Princen 1979). Rapeseed is grown across the border in Canada, so it likely can be cultivated in Montana. Yields at the Agricultural Experiment Station in Sidney, Montana (Bergman and Anderson 1982) have been low because

rapeseed needs cooler Julys than are found in this portion of Montana. According to Bergman, however, areas in the North Central district and at higher elevations would have more favorable results because July temperatures tend to be cooler than at Sidney, Montana.

Crambe abyssinica (Crambe) - Crambe seed contains 30 to 40 percent oil with up to 60 percent of it erucic acid. Though a native of western Europe and Central Asia, Crambe has been grown semi-commercially on several thousand acres all across the United States. Experimental plots near Bozeman, Montana yielded up to 1,712 pounds of seed per acre in 1962 and 1,902 pounds in 1963 when planted early in the growing season. Seed oil levels were 30.5 and 38.1 percent, respectively, for the two years. (White and Higgins 1964). Protein levels reported in USDA research (Barclay and Earle 1974; Jones and Earle 1964; Earle and Jones 1962) range from 25.0-31.5 percent. More recent Montana plantings yielded from 330 lbs/acre to 1,610 lb/acre during 1973 to 1977 (Bergman and Anderson 1981). The seed meal contains the natural toxins glucosinolates; but proper processing creates a meal useful for beef cattle feeding (Princen 1979).

The Sidney, Montana, test trials and the work of Georing, Eslick, and Brelsford (1965) indicate that this species is adaptable to Montana, though yields vary widely by year and by time of season when seed is planted.

Cucurbita foetidissima (Buffalo Gourd) - This species' seeds contain up to 40 percent oil and can yield up to 2 barrels of oil per acre. According to researchers at the University of Arizona (cited in Morgan and Shultz 1981), Buffalo Gourd oil has been tested as a diesel fuel with good results. The seed meal can provide a good feedstuff and the roots produce a large amount of starch, which could be converted to alcohol.

Buffalo Gourd is native to arid lands largely in the southwestern United States and likely would not readily adapt to Montana's cooler temperatures and shorter growing season. Populations have been found as far north as Laramie, Wyoming which is the extreme limit of the species' current range.

Euphorbia lathyris (Gopher Weed, Gopher Plant, Mole Plant) - This plant was introduced from the Mediterranean and is now widely naturalized in California and other parts of the United States. The latex substance found throughout the plant is a possible petroleum substitute and yields of 8 to 10 barrels per acre of petroleum-like compounds have been reported; however the plant appears to need a seven-month growing season to produce yields equivalent to sunflower which matures in four months (Sachs, Low, MacDonald, Awad and Sully 1981). Though certain populations are perennial, plants are extremely frost sensitive and would not survive through the winter. 1/ Consequently, adequate yields would be difficult to obtain in Montana's short growing season.

Lesquerella sp. (Bladderpod) - Approximately 20 members of this genus are native to central and south central United States. Those that have been analyzed produce seed with 20 to 40 percent oil. Montana already has three members of this genus: *L. alpina*, *L. curvipes*, and *L. ludoviciana*. 2/ Other members of this genus might be examined for adaptability to Montana.

1/ John Preese 1982: personal communications.

2/ All three species were included in the survey, though *L. curvipes* was eventually eliminated because it is so rare. Both of the remaining species fruit early in the season, precluding plant sampling in this study.

Limnanthes sp. (Meadowfoam) - *Limnanthes* species are indigenous to the Pacific Coast of the United States. Seed oil levels range from 25 to 33 percent for this genus, whose oil contains more than 95 percent fatty acids with potential utility in waxes, lubricants, and plasticizers. Higgins, Calhoun, Willingham, Dinkel, Raister, and White (1971) agronomically evaluated this genus by growing its members in experimental plots in northern California, Maryland, Oregon, and Alaska. Its distribution indicates that Montana is likely too arid for *Limnanthes* species to be grown successfully there. No members of the genus are currently found in Montana.

Lunaria annua (Money Plant or Honesty) - This plant already is grown commercially as an ornamental and for dried flowers. The seed, however, contains up to 40 percent oil. Though it grows best in Northern states, it is cultivated in northeastern United States and prefers mild, wet winters, so Montana may be too arid and cold for it.

Ricinus communis (Castor) - This tropical species already is grown commercially for its oil. Because 90 percent of the fatty acids available from castor oil is ricinoleic acid (Morgan and Shultz 1981) it may have potential as a chemical source. Castor grows as an annual in the United States and can grow with adequate rainfall, but needed to be irrigated in Texas and New Mexico, so it would not be adaptable to dryland agriculture in Montana. Additionally, Montana's growing season may be too short for a good seed set.

Sapium sebiferum (Chinese Tallow Tree) - This species is a prolific fat and oil producer, with yields up to 12 barrels of oil per acre (Morgan and Shultz 1981). The oil produced has properties similar to those of linseed oil. Unfortunately, it grows only on wet land in and along the southeastern Atlantic

and Gulf Coasts of the United States and would not be suitable for Montana.

Simmondsia chinesis or californica (Jojoba) - This plant is native to the arid southwestern United States and northern New Mexico. Its oil is almost 100 percent liquid wax esters, which are used extensively by the lubricant industry. Wild stands of Jojoba have been harvested in Baja California and in the Sonoran Desert. Plantations have been started in the southwestern United States, Mexico, Israel, Australia and South Africa. Because it is extremely sensitive to frost, it would not be adaptable to Montana.

Stokesia laevis (Stokes' Aster) - This species has been used as an ornamental in eastern and southwestern United States. The seed contains up to 40 percent oil of which 75 percent is epoxy acids. It is found naturally in southeastern Untied States, but not west of the Mississippi river. It is primarily concentrated in southern Mississippi, and in adjacent Louisiana and southern Alabama (Gunn and White 1974). Given this species' distribution, Montana is likely too arid and cold for it to be cultivated here.

Vernonia pauciflora and Vernonia anthelmintica - Neither species is native to the United States with the former from East Africa and the latter from India. Seed oil levels are, respectively, 23 to 31 and 40 to 42 percent. Because Vernonia species appear to require short days for good flowering and seed setting (Princen 1979), they likely will not be adaptable to the long days of the Montana growing season.

To summarize, species with the greatest near-term potential in Montana are Brassica napus, B. campestris, and Crambe abyssinica. The first two already are cultivated in Canada and likely could be readily

adapted to Montana especially in the North Central district and at high elevations where Julys tend to be cooler. Crambe, though not commercially grown, has been shown to produce good yields in Montana, provided it is planted early in the season (Higgins and White 1964; Bergman and Anderson 1982). Thus, this species likely could be readily adapted to Montana.

Though members of the Lesquerella (Bladderpod) genus may have potential in Montana, realizing their potential is likely much longer term than for Rapeseed or Crambe. Any Lesquerella species found to produce high levels of oil and adaptable to Montana would likely have to undergo extensive testing and breeding because very little agronomic research has been performed on this group.

As outlined above, the remaining species (e.g., Jojoba, Buffalo Gourd, Gopher Weed, Money Plant, Castor) likely have habitat constraints that would make them difficult (or impossible) to adapt to cultivation in Montana.

B. The Georing, Eslick, and Brelsford (1965) Work on the Cruciferae (Mustard Family)

Table V-1 presents oil and protein levels for nonnative mustards 3/ examined by Georing, Eslick and Brelsford (1965). Those with the highest average oil content are *Brassica chinensis* (48.8 percent), *Brassica besseriana* (34.1 percent), *Raphanus sativa* (34.0 percent), *Cambe abyssinica* (32.2 percent) and *Brassica carinata* (32.2 percent). All have protein levels as high or higher than cottonseed (24.9 percent), an oilseed species considered a source of high quality feed meal.

3/ Cultivated varieties already used as oilseeds and examined by this study were not included in this table because these are examined in detail in other portions of this report.

All of the species listed in Table V-1 were grown in Montana State University Experiment Station plots to obtain seeds for analyses and to evaluate the species agronomically. Of those with high oil content, Crambe absyssinica grows well in Montana, Raphanus sativa fairly well and Brassica carnata only moderately well. 4/ No information could be obtained on Brassica besseriana.

4/ Robert Eslick 1982: personal communications.

Table V-1. Species examined by Georing, Eslick and Brelsford (1965) which do not naturally grow in Montana

Species	Average % oil	Average % protein
Brassica besseriana	34.1	30.3
B. carinata	32.2	32.9
B. chinensis	48.8	20.8
B. pervidis	31.3	31.6
Crambe abyssinica	32.2	25.2
Eruca sativa	28.6	34.4
Iberis amara	22.2	35.6
Matthiola bicornis	25.9	33.0
Nasturtium officinale	21.6	28.9
Raphanus sativa	34.0	33.4
Rapistrum rugosum	10.5	12.1

Source: K. J. Georing, Robert Eslick and D. L. Brelsford, "A Search for High Erucic Acid Containing Oils in the Cruciferae," Economic Botany 19(1965):251-256.

VI. SOILS FOR OIL CROP PRODUCTION

Of Montana's 93 million acres, approximately 16.3 million and 46.6 million acres are currently in dryland crop and range respectively. Slightly less than 3 million acres are in irrigated crop production (Phillips 1981). Most of the dryland crop acreage is located in north central (the Triangle) and northeastern Montana (See Figure VI-1). Smaller acreage concentrations are found in the Judith Basin and near Billings.

Production of oil crops is currently in competition for the dryland cultivated acreage with wheat and barley. Expansion of acreage for all crop production, including oil crops, will involve land currently utilized as range. The purpose of this section is to examine Montana's land resources for potential oil crop production. Attention will be given to potential acreages, productivity and adaptation.

A. Soil Association

A soil association is a grouping of soil series, or types, based upon similarities of characteristics. The USDA-SCS has identified soil associations for publication of a Montana General Soils Map (USDA 1978). Although the map has been published, it is not yet released for general distribution. Acreage estimates of land cover for each soil association are from an M.S. thesis by Phillip Smith (1981). The information was digitized from LANDSAT imagry.

Use of soil association and land cover data require certain assumptions. Soils which are already extensively utilized for dryland crop production are most likely to be used for oil crop production as well as acreage expansion. Proximity to areas of current crop production is also important. Areas to be developed are likely to be near current farms and close to essential services, particularly transportation. Therefore, major soil associations have been divided into three groups.

Figure VI-1. Generalized Montana Cropland Areas

1. Soils of current importance for dryland crop production.
2. Soils of secondary importance for dryland crop production.
3. Soils predominantly in range production but with limited potential for cultivation.

These areas are shown in Figure VI-2.

1. Soil Associations of Current Importance

Soil associations in Group 1 have the greatest productivity under cultivation without irrigation. Oil crop production could take place on currently cultivated portions providing that it was economically competitive with small grains. Uncultivated portions, now in rangeland, are prime candidates for expansion. In fact, many of these areas have been occasionally cultivated as economic conditions fluctuate.

Soil associations of Group 1 are shown in Table VI-1 with descriptive information and acreages. Table VI-2 presents the representative soil series in each association. Approximately 64 percent of this group of soil associations is currently cultivated. Approximately 12.5 thousand acres are irrigated or less than 1 percent of the state's irrigated acreage. The Group 1 associations also account for 57 percent of Montana's dryland crop acreage. They are primarily associated with the glacial till plains of Northern Montana. The areas were created or influenced by continental glaciation. One soil association, mapping unit Sg, contains over 31 percent of the state's dryland crop acreage. Representative soil series are Scobey, Kevin, Telstad, and Chinook. These are the commonly farmed soils of the Triangle area. A significant portion of the uncultivated soil in mapping unit Sg is in northeastern Blaine, northern Phillips, and Valley counties.

2. Soil Associations of Secondary Importance

Soils in Group 2 are similar to those in Group 1 in degree of cultivation but of lesser importance for two reasons:

Figure VI-2. Selected Soil Associations

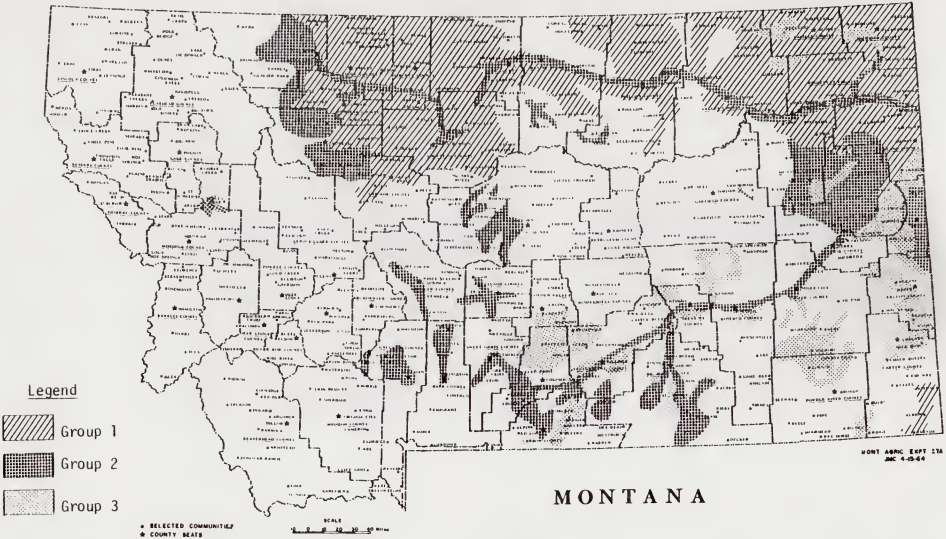

Table VI-1. Group 1 soil associations of current importance for dryland crop production

Mapping unit symbol	Association description	Cropland (Thousand acres)	Range (Thousand acres)	Location of major areas
Og	Mollisols - Entisols: undulating to strongly rolling soils on glacial till plains	2,377	1,230	Northwestern Montana
Oh	Entisols - Mollisols: Strongly rolling to steep dissected glacial till plains	458	452	Northeastern Montana
Ot	Mollisols: Nearly level to strongly sloping terraces	296	62	Northeastern Montana
Sg	Mollisols - Aridisols: Nearly level to hilly soils on glacial till plains	5,141	2,897	Triangle area, northern Phillips and Valley counties
St	Mollisols: Nearly level to moderately steep outwash and stream terraces	304	57	Triangle area
Vb	Aridisols - Mollisols - Entisols: Nearly level to strongly sloping soils on terraces, fans, and basins	818	412	Triangle area
		9,394	5,110	

Table VI-2. Representative soil series found in the soil associations of Group 1 (see Table VI-1)

Mapping unit symbol	Soil series names
Og	Bearpaw, Farnuf, Lambert, Shambo, Vida, Williams
Oh	Lambert, Vida, Williams, Zahill
Ot	Dooley, Farnuf, Manning, Tally, Turner, Wabek
Sg	Chinook, Elloam, Joplin, Kevin, Scobey, Sunburst, Telstad, Thoeny
St	Assiniboine, Chinook, Ethridge, Evanston, Floweree, Kremlin
Vb	Absher, Gerdrum, Linnet, Havre, Marias, Nobe, Scobey, Vanda

1. They are lower in productivity or have restrictions to cropping.
2. Individual areas are small and scattered.

Table VI-3 shows descriptions and acreages of the Group 2 associations. Table VI-4 gives the representative soil series for each association. Most of the soils are distinguished by formation in alluvium and tend to be of mixed mineralogy. Geographically, much of the acreage is located near the Group 1 soil associations.

Most of the irrigated land in Montana is associated with major river drainages or located in intermountain valleys. Due to the dispersed nature of the areas, a significant portion (33%) of the state's irrigated acreage is included in the Group 2 soil associations. The nonirrigated portions of this group contain 15 percent of the state's total dryland acreage. The dryland areas are restricted in productivity primarily by elevation or shortened growing season (GB); salinity and sodicity (Ap), slope (Np) and availability of irrigation water. The portions of the areas currently used for rangeland have similar, though more severe, restrictions.

3. Soils with Limited Potential for Cultivation

The soil associations in Group 3 are located on the sedimentary bedrock plains of eastcentral and southeastern Montana. The sedimentary plains are generally dissected with dispersed areas suited to cultivation. This is also an area of drier climate and higher temperatures causing low water use efficiency.

Group 3 soils have the least potential for cultivation. Due to climate, slope, or other restrictions they are primarily suited to permanent vegetative cover. A number of restrictions would have to be overcome before the land use could be changed. These lands are fragile and the erosion hazard with cultivation is severe. Due to the current use, soils in Group 3 are the farthest distance from the established supply and distribution network.

Table VI-5 shows the soil associations included in Group 3 and their cropland acreages. Table VI-6 lists representative soil series

Table VI-3. Group 2 soil associations of secondary importance for dryland crop production

Mapping unit symbol	Association description	Dryland	Irrigated (Thousand acres)	Range	Location of major areas
Ap	Entisols - Aridisols - Inceptisols Mollisols: Nearly level to strongly sloping soils on low terraces, fans and flood plains	43	530	412	All major floodplains
Gb[1/]	Mollisols: Nearly level to steep soils on fans, benches and terraces	1,034	288	1,739	Judith Basin, Intermountain valleys east of divide, west of Triangle
Nb	Mollisols: Nearly level to steep soils on fans, benches and terraces	180	41	154	Glendive, Great Falls
Np[2/]	Mollisols - Entisols: Nearly level to strongly sloping soils on sedimentary bedrock plains	983	--	962	Glendive, Lodge Grass
Pb	Mollisols - Aridisols: Nearly level to steep soils on fans, benches and terraces	190	118	139	Fairfield (Southern Triangle)
		2,430	977	3,406	

1/ Excludes unit Gb3.

2/ Excludes units Np2 and Np3

Table VI-4. Representative soil series found in the soil associations of Group 2 (see Table VI-3)

Mapping unit symbols	Soil series names
Ap	Alona, Busby, Glendive, Harlem, Havre, Havrelon, Lohler, Lonna, Savage, Trembles
Gb	Amsterdam, Beaverton, Bozeman, Castner, Fairfield, Farnuf, Grantsdale, Hilger, Judith, Martinsdale, Perma, Sweetgrass, Windham
Nb	Azaar, Farland, Farnuf, Lihen, Savage, Turner
Np	Bitton, Cabba, Doney, Reeder, Regent, Wayden
Pb	Abor, Binna, Crago, Dutton, Evanston, Kobar, Rothiemay

Table VI-5. Group 3 soil associations with limited potential for cultivation

Mapping unit symbol	Association description	Cropland (Thousand acres)	Range (Thousand acres)	Location of major areas
Nh[1/]	Entisols - Inceptisols - Mollisols: Strongly sloping to steep soils on sedimentary bedrock plains and hills	967	1,694	Northeast Montana
Ph[2/]	Entisols - Mollisols: Strongly sloping to steep soils on dissected sedimentary bedrock plains and hills	278	355	Marias River floodplain (Triangle)
Pp	Mollisols - Aridisols: Nearly level to strongly sloping soils on sedimentary bedrock plains	324	674	Northern Stillwater County
Tb	Aridisols - Mollisols: Nearly level to steep soils on fans, benches, and terraces	247[3/]	437	Southcentral Montana
Tp[4/]	Aridisols - Entisols: Nearly level to moderately steep soils on sedimentary bedrock plains	448	1,049	Scattered areas of Southeastern Montana
		2,264	4,209	

1/ Excludes units Nh2 and Nh3

2/ Includes only unit Ph2

3/ 52% of the listed cropland acreage is irrigated

4/ Includes only map units Tp1 and Tp5

Table VI-6. Representative soil series found in the soil associations of Group 3 (see Table VI-5)

Mapping unit symbols	Soil series names
Nh	Cabbart, Cambert, Cherry, Dast, Dimyaw, Lambert, Lawther, Macar, Shambo, Tinsley, Utica, Windham, Wayden
Ph	Cabbart, Glendive, Havre, Lisam, Rentsac, Windham
Pp	Beemom, Bonfri, Boxwell, Brussett, Chinook, Ernen, Marmarth, Sinnigam, Tanna, Yawdim
Tb	Absher, Attewan, Creed, Evanston, Fort Collins, Keiser, Kobar, Lonna, Yamac
Tp	Absher, Bonfri, Busby, Cambeth, Cambett, Delpoint, Gerdrum, Kremlin, Lonna, Marmarth, Yamac

for each association. Approximately 13 percent of the state's dryland crop production is found on these units. On unit Tb, 52 percent of the cropped acreage (129 thousand A) is irrigated. The irrigated portion is in Carbon and Yellowstone Counties.

B. Cropping Potential

Examination of soil associations and land cover at a broad scale provides a starting point for studying cropping potentials. Major areas of soils suitable for crop production were identified and their potential stratified for further investigation. The soil mapping units summarized contain 85 percent of the state's dryland crop acreage. Associated with the cultivated areas are nearly 13 million acres of rangeland. It is on this land base that oil plant production could occur.

The mapping units studied contain a wide variety of soil and climatic types. We can assume that the most suitable land is already in cultivation. A portion of the rangeland, perhaps 20 to 30 percent, could be cultivated with care or cultivated occasionally. Much of this rangeland has been cultivated in the past and fluctuates between cultivation and range. Experience in Montana has shown that unless special precautions are taken, many soils can be severely damaged.

Some cautions are in order when considering the data used in this study. The mapping scale used is 1:1,000,000 so that each mapping area may include significant acreage of other units. Thus, acreage estimates will be optimistic due to inclusion of rough land. Measurements of variability within mapping units are not available. It should also be noted that present land ownership was not considered. Large areas of Eastern Montana are in the public domain and may not be available for crop production. More detailed study will be required to fully assess the potential for expanded production.

If plants are selected for further study, and their environmental characteristics investigated, the approach used in this task would be appropriate for targeting specific areas for production. The maps used for this task are part of a group prepared by state and federal

agencies. Other characteristics which could be "overlain" are mean annual precipitation, growing season precipitation, frost-free period and evaporative demand. Unfortunately land ownership has not been mapped at the same scale but could possibly be obtained from the Montana Department of Community Affairs.

After specific areas are targeted for production, field trials with the plants and more detailed studies could be undertaken. More detailed soils work could be done where the National Cooperative Soil Survey has been published or is nearly completed. Counties within the soil associations outlined in this task with detailed soil surveys include Big Horn, Cascade, Dawson, Glacier, Richland, Sheridan, Stillwater, Yellowstone and Wibaux. These surveys provide more specific data on suitability of specific soils for crop production.

C. Crop Adaptation

Very little information is available concerning the soil and climatic adaptation of the plants sampled in this study. However, some comparison may be drawn with crops currently grown for oil in Montana.

Safflower is the leading oil seed crop in the state. The primary production areas are the eastern side of the Triangle and the northeastern corner of the state. The soil associations involved are Sg and Og, both in Group 1. The primary restriction for safflower production is growing season length. At least 110 to 120 days are required, with the crop maturing better with warmer night temperatures. This is why production is restricted to the eastern Triangle. Safflower has a maximum rooting depth of 8 to 9 feet and will penetrate dry soil layers to reach deeper soil water. These features make it important in dryland rotations. Production of safflower under irrigation has been successful in the Yellowstone valley with yields of up to 2500 pounds of seed per acre. Dryland yields under good soil and climatic conditions are 1000 pounds on recrop and 2000 pounds following fallow.

Sunflowers have been grown successfully though not as extensively as safflower. An advantage of sunflowers is a shorter growing season requirement. Some disadvantages of sunflowers are shallower rooting

depth (less drought tolerance), reduction of yield by birds and insects and the need for row planting equipment. Yields of sunflowers are typically slightly less than for safflower.

Flax, mustards and rapeseed have been grown successfully in Montana as markets allow. These crops generally do best with cooler temperatures. Therefore, production has been along the Hi-Line (U.S. Highway 2) and near the Canadian border. Flax has been found to perform acceptably on marginal land.

VII. CROP BUDGETS

Using crop budgets, we examined the economics of cultivating oilseed crops suitable for Montana soil and climatic conditions. Due to the preliminary nature of this analysis, projections of crop budgets could not be made for plants lacking extensive plot-yield tests. Hence, only six oilseed crops that have been grown in Montana (either experimentally or commercially) were examined: sunflower, safflower, rapeseed, mustard, flax, and crambe. Because there is no established market for crambe, only estimations of cost could be made for it.

In order to compare the economics of producing oilseed crops with that of small grains, crop budgets were also prepared for wheat and barley.

A. General Methodology

Estimations of costs, yields, and revenues, which make up the crop budgets, are difficult because of Montana's diverse soil and climatic conditions. Budgets presented represent average conditions in the dryland agricultural areas in the state. The per-acre budgets represent an intensive management effort to obtain the most economical yields for each crop; all crops are assumed to have been adequately treated with insecticides, herbicides, and fertilizer.

Yields for each crop budget were obtained from experiments at the Eastern Agricultural Research Center near Sidney, Montana, for all crops except rapeseed and mustard. The yields used in the crop budgets represent average per acre yields from trials for numerous years as described in Chapter II. Per acre yields for rapeseed and mustard are average yields from various sites in the Golden Triangle during the 1977 and 1978 crop years. The averages included all rapeseed trials conducted on fallow at sites near Conrad, Cut Bank, Dutton, and Sunburst

and all mustard trials near Conrad, Cut Bank, Dutton, Power, Sunburst, Chinook, and Chester.

In all cases, yields in the crop budgets are higher than those obtained in statewide, on-farm cultivation of each oilseed crop. Yields from experiment station trials are higher because of special attention received; i.e., weeds are more closely controlled, sufficient fertilizer applications are made, and seed losses at harvest are minimized. The yields and corresponding crop budgets, which represent potential yields and profits obtained through an intense management effort, are compared with crop budgets derived in the same manner for wheat and barley, so the analysis permits comparisons between oilseed crops and Montana's more conventional crops.

Prices used in the crop budgets represent prices paid farmers in late fall 1982 for oilseeds delivered to local elevators and processing plants. The prices are for high or number one grade grains.

Costs for seed, machinery fuel and lube, machinery repair, labor, ownership costs, and general farm overhead costs were derived from actual farm costs, developed using the crop budget generator that the Department of Agricultural Economics, Oklahoma State University developed for the Economic Research Service, U.S. Department of Agriculture. For oilseed crops lacking per-acre budgets estimated by the above source in Montana, costs were estimated by using estimates from nearby states (e.g., North Dakota) or from crops with similar operational requirements. All costs were updated to 1982 conditions by appropriate indices.

Costs for herbicides and insecticides were estimated from studies conducted on oilseed crops in Minnesota, North Dakota, South Dakota, Idaho, and Montana. The costs were updated to mid-1982 by the Agricultural Chemicals Index.

The wide range of soil characteristics (including nutrients in the soil) in Montana makes estimating fertilizer costs difficult. Optimal fertilizer applications depend on soil moisture, soil nitrate-nitrogen, soil phosphorus, crop and fertilizer prices, precipitation, and many other factors. For purposes of this analysis, fertilizer costs for all crops were computed for 80 pounds of nitrogen and 20 pounds of P_2O_5 plus \$3 per acre for applying the fertilizer.

Management costs and interest on operating capital were computed as a portion of other costs, management as 10 percent of all other costs excluding land. Interest on operating capital was based on costs of borrowing all other variable costs and general farm overhead costs at a rate of 12 percent for six months. (Other variable costs include costs of seed, herbicide, insecticide, fertilizer, machinery fuel and lube, machinery repair and labor.)

Land costs were based on 1982 rental rates in Montana.

B. Oilseed Crop Budgets

Tables VII-1 through VII-6 present the estimated per-acre costs and revenues, respectively, for growing sunflower, safflower, flax, mustard, rapeseed, and crambe. The budgets are in three sections: variable costs, fixed costs, and revenues. All costs and prices are current (1982).

An important factor is that prices for oilseed crops fell substantially the past year. Prices for flax and sunflower went down 20 percent between November 1981 and November 1982. Prices for other oilseed fell 15 to 25 percent during the same time period. With price declines of this magnitude, it is not surprising that all the crop budgets presented, including those for Montana's conventional crops show costs higher than revenues.

1. Flax

Table VII-1 displays costs and revenues for flax. Costs per acre exceed \$140, more than \$55 of which are variable (or direct) costs. Flax yields are estimated to be 17.7 bushels per acre, which at \$5.20 a bushel, the current (October 1982) price means revenues of approximately \$92 per acre, and per-acre losses exceeding \$48. Even with the land cost omitted an \$8.06 per acre loss is incurred with 1982 prices.

Table VII-1. Per acre crop budget in dollars for flax production

Budget item			
Revenue			92.04
Yield: 1/./ bu/acre 1/			
Price: $5.20/bu			
Variable costs			
Seed	4.29		
Herbicide, Insecticide	3.00		
Fertilizer	26.40		
Machinery fuel and lube	6.65		
Machinery repair	5.56		
Labor	5.88		
Interest on operating capital	3.66		
Total variable costs		55.44	
Fixed costs			
Ownership costs 2/	26.37		
Land	40.00		
General farm overhead	9.19		
Management	9.10		
Total fixed costs		84.66	
Total costs			140.10
Net gain (loss)			(48.06) 3/

1/ Average yield from experiment station trials at the Agricultural Research Center, Sidney, Montana, during 1976-1982.

2/ Represents costs of replacing equipment, taxes, interest, and insurance.

3/ Even with the land cost omitted, an $8.06 per acre loss is incurred with 1982 prices.

Table VII-2. Per acre crop budget in dollars for sunflower production

Budget Item			
Revenue			98.64
Yield: 1,233 lb/acre 1/			
Price: $8.00/cwt			
Variable costs			
Seed	5.85		
Herbicide, Insecticide	11.22		
Fertilizer	26.40		
Machinery fuel and lube	11.22		
Machinery repair	7.69		
Labor	8.90		
Drying	2.47		
Interest on operating capital	5.10		
Total variable costs		78.85	
Fixed costs			
Ownership costs 2/	28.61		
Land	40.00		
General farm overhead	9.19		
Management	11.86		
Total fixed costs		89.66	
Total costs			168.51
Net gain (loss)			(69.87) 3/

1/ Average yield from experiment station trials at the Agricultural Research Center, Sidney, Montana, during 1976-1981.
2/ Represents costs of replacing equipment, taxes, interest, and insurance.
3/ Even with the land cost omitted, a $29.87 per acre loss is incurred with 1982 prices.

Table VII-3. Per acre crop budget in dollars for safflower production

Budget Item			
Revenue			129.00
Yield: 1,290 lb/acre 1/			
Price: 10¢/lb			
Variable costs			
Seed	8.78		
Herbicide, Insecticide	8.07		
Fertilizer	26.40		
Machinery fuel and lube	8.25		
Machinery repair	6.63		
Labor	7.27		
Interest on operating capital	4.48		
Total variable costs		69.88	
Fixed costs			
Ownership costs 2/	28.14		
Land	40.00		
General farm overhead	9.19		
Management	10.72		
Total fixed costs		88.05	
Total costs			157.93
Net gain (loss)			(28.93) 3/

1/ Average yield from experiment station traisl at the Agricultural Research Center, Sidney, Montana, during 1973-1981.
2/ Represents costs of replacing equipment, taxes, interest, and insurance.
3/ With the land cost omitted, an $11.07 per acre gain is shown with 1982 prices.

Table VII-4. Per acre crop budget in dollars for rapeseed production

Budget Item			
Revenue			106.20
Yield: 885 lb/acre 1/			
Price: 12¢/lb			
Variable costs			
Seed	2.00		
Herbicide, Insecticide	6.83		
Fertilizer	26.40		
Machinery fuel and lube	6.65		
Machinery repair	5.56		
Labor	6.10		
Interest on operating capital	3.76		
Total variable costs		57.30	
Fixed costs			
Ownership costs 2/	27.41		
Land	40.00		
General farm overhead	9.19		
Management	9.32		
Total fixed costs		85.92	
Total costs			143.22
Net gain (loss)			(37.02) 3/

1/ Average yield for Montana State University Cooperative Extnesion Service trials at sites near Conrad, Cut Bank, Dutton, and Sunburst during 1977 and 1978.
2/ Represents costs for replacement of equipment, taxes, interest, and insurance.
3/ With the land cost omitted, a $2.98 per acre gain is shown with 1982 prices.

Table VII-5. Per acre crop budget in dollars for mustard production

Budget Item			
	Yellow	Brown	Oriental
Revenue	79.92	49.38	73.98
Yield 1/ (lb/acre)	888	823	1,233
Price	9¢/lb	6¢/lb	6¢/lb
Variable costs			
Seed		2.00	
Herbicide, Insecticide		6.83	
Fertilizer		26.40	
Machinery fuel and lube		6.65	
Machinery repair		5.56	
Labor		6.10	
Interest on operating capital		3.76	
Total variable costs			57.30
Fixed costs			
Ownership costs 2/		27.41	
Land		40.00	
General farm overhead		9.19	
Management		9.39	
Total fixed costs			85.99
Total costs			143.29
Net gain (loss)	(63.37)	(93.91)	(69.31)

1/ Average yield from experiment station trials in or near the Golden Triangle at sites near Power, Conrad, Sunburst, Chinook, Dutton, Cut Bank, and Chester in 1977 and 1978.

2/ Represents costs or replacing equipment, taxes, interest, and insurance.

Table VII-6. Per acre crop budget in dollars for crambe production

Budget Item		
Revenue		
Yield: 1,086 lb/acre 1/		---
Price: No market established		
Variable costs		
Seed	4.00	
Herbicide, Insecticide	7.00	
Fertilizer	26.40	
Machinery fuel and lube	8.00	
Machinery repair	6.80	
Labor	8.00	
Interest on operating capital	4.16	
Total variable costs		64.36
Fixed costs		
Ownership costs 2/	27.41	
Land	40.00	
General farm overhead	9.19	
Management	10.10	
Total fixed costs		86.70
Total costs		151.06
Net gain (loss)		

1/ Average yield from experiment station trials at the Agricultural Research Center, Sidney, Montana, during 1973-1977.

2/ Represents costs for replacement of equipment, taxes, interest, and insurance.

2. Sunflower

Sunflowers are the most expensive crop to grow of the six crops considered. Total variable costs are estimated to be \$78.85 while fixed costs are \$89.66 for total costs of \$168.51 per acre (Table VII-2). Revenues on yields of 1,233 pounds of seed per acre at \$8 per hundredweight totaled \$98.64. The net loss from growing sunflowers under those conditions totaled \$69.87 per acre. Even with the land cost omitted, a \$29.87 per acre loss is incurred with 1982 prices.

3. Safflower

Table VII-3 displays the crop budget for safflower. Total variable costs are \$69.88 and fixed costs are \$88.05 for a total production cost of \$157.93. With a yield of 1,290 pounds per acre and current prices (October 1982) of 10¢ per pound, revenues total \$129 for a net loss of nearly \$29 per acre. With the land cost omitted, an \$11.07 per acre gain is shown with 1982 prices.

4. Rapeseed

The per acre crop budget for rapeseed (Table VII-4) indicates variable costs of \$57.30 and fixed costs of \$85.92 for total costs of more than \$143 per acre. Yield, estimated from experiments conducted by the Montana State University Cooperative Extension Service in 1977 and 1978 (Jackson, 1979) at various sites in the Golden Triangle averaged 885 pounds per acre so in 1982, with rapeseed selling for 12¢ per pound, losses would exceed \$37 per acre. With land cost omitted, the gain is \$2.98 per acre.

5. Mustard

Crop budgets for yellow, brown and oriental mustard are presented in Table VII-5. Costs were estimated to be the same for all three, with yields and seed prices the only differences.

Costs for growing mustard total just more than \$143 per acre, nearly \$86 of which is fixed costs. Yields are 888, 823, and 1,233 pounds for yellow, brown, and oriental varieties, respectively. Prices are 9¢ per pound for yellow mustard and 6¢ per pound for both brown and oriental mustard. Per acre losses total approximately \$63 for yellow, \$94 for brown, and \$69 for oriental mustard.

6. Crambe

Crop production costs for crambe (Table VI-6) are expected to be in the same range as those for other oilseeds. The only possible difference is that crambe will probably always require swathing because seeds disperse before the crop is ready to be combined. Total production costs are estimated to be approximately \$151 per acre. Yields were 1,086 pounds per acre. As no market price is available for crambe, revenues cannot be estimated.

C. Small Grain Crop Budgets

In order to compare the economics of producing oilseed crops with that of small grains, crop budgets were prepared for wheat and barley using the same general methodology described above. Yields were obtained from experiment station yield trials conducted at the Eastern Agricultural Research Center in Sidney, Montana; all machinery costs, seed costs, ownership costs and general farm overhead were average estimates from crop budgets developed for the USDA by the Department of Agricultural Economics at Oklahoma State University. Fertilizer costs represent the cost of 80 pounds of nitrogen and 20 pounds of P_2O_5. Land costs represent land rental costs in Montana.

It is important to understand that despite the fact that growers of wheat, barley and the oilseed crops currently grown experience a net loss, they are making a rational decision in continuing production. (Assuming that producers believe this situation will not prevail in the long run.) As long as revenues cover more than the variable (or direct)

costs associated with the cultivation of the individual crop, farmers should continue to grow said crop. Any revenues earned over the variable costs can be applied to the fixed costs associated with farm ownership. These fixed costs can only be avoided by selling the farm enterprise.

Tables VII-7 and VII-8 display the estimated costs and revenues associated with the production of wheat and barley. Total costs for each crop are estimated to be approximately \$160 per acre. Revenues for spring wheat totaled over \$140 per acre while barley revenues were somewhat less than \$120 per acre.

D. Summary

Generally, agricultural markets in the U.S. in October, 1982, were low and supplies were large. Oil-bearing crops are a prime example with prices falling an average of 30 percent a bushel from May 1981 to May 1982. This price decline stems primarily from recent worldwide record production of oilseed crops.

In Montana, prices are expected to continue to decline over winter for the main oilseed crops, safflower and sunflower. Long-term contracts for the 1983 safflower crop specify prices of about \$180 per ton compared with 1982 contracts for \$200 per ton. Similar declines are expected in sunflower prices.

Rapeseed and mustard markets are dominated by Canadian markets, which are affected by government programs that include deficiency payments to help producers cover their costs and that cause markets to stay out of balance longer as production does not decline as rapidly when prices decline as it would if markets were not affected by government programs. For that reason, rapeseed and mustard markets may be characterized by very low prices compared to production costs for some time to come.

Table VII-7. Per acre crop budget in dollars for wheat production

Budget item	Wheat	
Revenue		140.58
Yield: 42.6 bu/A 1/		
Price: $3.30/bu		
Variable costs		
Seed	4.61	
Herbicide, Insecticide	5.86	
Fertilizer	26.40	
Machinery fuel and lube	9.92	
Machinery repair	6.84	
Labor	7.59	
Interest on operating capital	4.22	
Total variable cost	65.44	
Fixed costs		
Ownership costs 2/	33.67	
Land	40.00	
General farm overhead	9.19	
Management	10.83	
Total fixed costs	93.69	
Total costs		159.13
Net gain (loss)		(18.55)

1/ Average yield from experiment station trials at the Agricultural Research Center, Sidney, Montana on numerous varieties, 1965-1981.
2/ Includes replacement of equipment, taxes, interest, insurance.

Table VII-8. Per acre crop budget in dollars for barley production

Budget	Barley	
Revenue		116.55
Yield: 55.5 bu/A 1/		
Price: $2.10/bu		
Variable costs		
Seed	3.51	
Herbicide, Insecticide	7.44	
Fertilizer	26.40	
Machinery fuel and lube	9.90	
Machinery repair	7.66	
Labor	8.00	
Interest on operating capital	4.33	
Total variable cost	67.24	
Fixed costs		
Ownership costs 2/	33.15	
Land	40.00	
General farm overhead	9.19	
Management	10.96	
Total fixed costs	93.30	
Total costs		160.54
Net gain (loss)		(43.99)

1/ Average yield from experiment station trials at the Agricultural Research Center, Sidney, Montana on numerous varieties, 1965-1981.

2/ Includes replacement of equipment, taxes, interest, insurance.

VIII. FEASIBILITY INDICATORS AND IMPACTS OF OILSEED CROP PRODUCTION

The economic feasibility of producing oilseed crops depends upon the costs and revenues associated with their production. The extent to which the oilseed and oil bearing crops may compete with currently produced crops may be assessed partially by comparing their costs of production. In order to fully assess the costs of producing plant oils for substitute fuels, certain processing steps and the impacts of plant fuel oil production need to be considered also.

A. Feasibility Indicators

The feasibility of producing the oilseed crops--flax, sunflower, safflower, rapeseed, mustard and crambe--may be assessed in terms of their present production methods and costs, and product uses. The economics of production of the oilseed crops can be readily compared to that of the small grains by use of crop budgets. However, the feasibility of producing the oilseed crops when the seed oil is to be used as an emergency substitute or extender for diesel fuel cannot be computed, unless a value can be given to the seed oil when used in lieu of diesel fuel. The cost of producing the seed oil cannot be compared directly to the present cost of diesel fuel since in an emergency situation diesel fuel would presumably be much more expensive, if available. Under these circumstances, the assessment of the costs of the seed oils computed from the costs of production and processing can be made, but no value can be given for their use in an emergency situation--a value that would need to be based on that of the crop saved.

Indicators of the feasibility of the seed oil are discussed below. Oilseed crop budgets are compared to crop budgets for wheat and barley. Vegetable oil market and production costs are examined and compared to

current diesel fuel prices. Other impacts such as changes in farming practices, land use, vegetable oil usage, and consumer and other economic impacts are discussed.

1. Crop Budget Comparisons

A comparison of the economics of oilseed production and that of small grains can be made by examining the crop budgets (Chapter VII). The costs, revenues and profits for the six oilseed crops, wheat and barley are summarized in Table VIII-1. Under current conditions, the profitability of wheat and barley production is approximately the same as the oilseed crops, with sunflowers and mustard having the poorest returns. If the land costs of $40 per acre are excluded, wheat, safflower and rapeseed show a net gain. If management costs are excluded also, then barley and flax too show a net gain. For all crops considered, the revenues greatly exceed the variable costs. (Since no market price has been established for crambe, no estimate of revenues can be made.)

It is important to understand that despite the fact that growers of wheat, barley and the oilseed crops currently grown experience a net loss, they are making a rational decision in continuing production. (Assuming that producers believe this situation will not prevail in the long run.) As long as revenues cover more than the variable (or direct) costs associated with the cultivation of the individual crop, farmers should continue to grow said crop. Any revenues earned over the variable costs can be applied to the fixed costs associated with farm ownership. These fixed costs can only be avoided by selling the farm enterprise.

2. Fuel Use Comparison

In order to make a meaningful assessment of the feasibility of plant oils as diesel fuel substitutes, a comparison of the breakeven seed or vegetable oil price with that diesel fuel price must be made. However, to assess the feasibility of plant oil use as an emergency

Table VIII-1. Comparison of economics of producing oilseed and small grain crops

Crop	Costs	Revenues	Profits	Profits omitting land costs
	($/acre)			
Wheat	159.13	140.58	-18.55	21.45
Barley	160.54	116.55	-43.99	-3.99
Flax	140.10	92.04	-48.06	-8.06
Sunflower	168.51	98.64	-69.87	-29.87
Safflower	157.93	129.00	-28.93	11.07
Rapeseed	143.22	106.20	-37.02	2.98
Yellow mustard	143.29	79.92	-63.37	-23.37
Crambe	151.06	No market	--	--

Source: Summary of Tables VII-1 to VII-8.

diesel fuel substitute when diesel fuel is unavailable requires an assessment of the value of the plant oils to the farmer and other economic entities in preserving agricultural production.

a. Plant oils costs

The crop budgets presented in Chapter VII indicate that the vegetable oil market is not now in equilibrium. Because current oilseed prices are so low, producers are likely to decrease production or store what they produce until prices rise, or do both. Because of the current imbalance, it costs more to produce a gallon of vegetable oil than to buy the oil on the open market. These two costs (production and market) likely will equalize as supply and demand for vegetable oil come into balance. Because producers cannot substantially cut costs per unit or production, they quite likely will decrease production, causing the market price for oil to rise until production costs and market prices balance.

Market prices in Montana for raw, unrefined vegetable oil in October 1982 for the five crops analyzed in this study were:

Crop	Oil price ¢/pound	Oil price $/gallon
Flax (linseed)	24.0	1.85
Sunflower	17.0	1.31
Safflower	17.5	1.35
Rapeseed	16.0	1.20
Mustard (yellow)	14.0	1.08

Linseed oil prices are the highest at $1.85 per gallon. Safflower oil prices are just slightly higher than sunflower oil. Rapeseed oil prices in Montana are $1.20 per gallon while mustard sells for $1.08 per gallon. No crambe oil prices are established.

Because volumes are low, prices are not well established. Markets are sketchy for flax (linseed), rapeseed, and mustard oil, especially in Montana. Flax is traded nationwide with market quotes made daily. Flax

prices in Montana are based on Minneapolis prices with downward adjustments for transportation. The rapeseed oil price represents oil with low erucic acid content. (High erucic acid rapeseed oil is a very small market going primarily to the chemical processing industry.) Most low erucic acid rapeseed is exported. Mustard oil prices are estimated from the few trades made in this commodity in Montana and the Northwest. Safflower and sunflower are actively traded throughout Montana and North Dakota.

Production costs per gallon of oil are based on crop budgets presented in the previous section and oil yields presented in Chapter II. Oilseed meal prices are for October 1982.

Oilseed meal prices may rise and help offset the high costs of producing oilseed crops. But for this analysis, the computed cost per gallon of oil is based on the assumption that prices for meal (which is less important economically than oil) will remain at current levels. That is a simplifying assumption, not necessarily an expected result.

Table VIII-2 summarizes the seed and oil yields for flax, sunflower, safflower, rapeseed, mustard, and crambe from analyses presented earlier. Meal yields also are calculated for each crop, assuming 4 percent shrinkage in weight during processing. Meal prices are those prevailing (October 1982) in Montana and the Northwest.

It is estimated that oilseed processors receive a processing margin of $20 per ton for all of the crops analyzed (Table VIII-2). While costs to process the different crops vary, accurate, crop-specific information could not be obtained. The $20 a ton is what processors are receiving under current market conditions. Processors, according to industry sources, are losing money because of the depressed vegetable oil and meal markets and excess processing capacities. To break even, i.e., cover fixed costs (costs for the crushing facility, management, etc.) and variable costs involved in crushing and extracting oil (much of which is energy costs) processors would need nearly double the $20 per ton.

Under estimated October 1982 conditions for farming costs, meal prices, and processing margins, it costs from $2 to $4 to produce a gallon of unrefined vegetable oil in Montana (Table VIII-2). Flax

Table VIII-2. Production cost, seed, oil, and meal yields, meal price, processing cost, and breakeven oil price for six oilseed crops grown in Montana

Crop	Production costs 1/	Seed yield 1/	Seed oil content	Oil yield 2/	Meal Yield 3/	Meal Price	Meal Value	Processing margins 4/	Breakeven oil price 5/
	$/acre	lbs/acre	percent	gal/acre	lbs/A	$/ton	$/acre	$/gal	$/gal
Flax	140.10	993	44	56.2	534	115	30.71	.18	2.13
Sunflower	168.51	1,233	41	65.0	698	80	27.92	.19	2.35
Safflower	157.93	1,290	36	59.5	792	60	23.76	.22	2.47
Rapeseed	143.22	885	40	45.5	510	70	17.85	.19	2.95
Mustard (yellow)	143.29	888	28	31.8	614	65	19.96	.28	4.16
Crambe	151.06	1,086	30	41.7	730	60 6/	21.90	.26	3.36

1/ Obtained from Tables VII-1 through VII-6.

2/ Calculated in Chapter II.

3/ Calculated as follows: [(Seed yield) (1-Seed oil content)] .96 = Meal yield.

4/ DPRA estimate based on an estimated processing margin of $20 per ton.

5/ Calculated as follows: $\frac{\text{Production costs - meal value}}{\text{Oil yield}}$ + processing cost = breakeven oil price

6/ Estimated on the basis of expected protein content.

(linseed oil) can be produced for about $2.13 a gallon while it costs approximately $4.16 per gallon for yellow mustard.

b. Diesel fuel costs

Retail diesel fuel prices (U.S. Department of Energy, 1982) increased steadily from 1976 to 1981 as shown below:

No. 2 diesel fuel

Year	Average retail price (¢/gal)
1976	34.7
1977	39.3
1978	40.2
1979	62.4
1980	87.3
1981	106.2
June 1982	102.2

The high prices of early 1981 declined somewhat up to mid 1982. The current price of about a dollar a gallon is well below the breakeven cost of all of the vegetable oils shown in Table VIII-2. For the near term, then the price of vegetable oils would preclude their being used as substitutes for diesel fuel. However, in a situation where diesel fuel was unavailable, the value of the plant fuel oils if used for harvesting a crop that would otherwise be lost could be quite high.

B. Impacts of Plant Oil Production and Use

Although oilseed and oil-bearing plants have the potential to supplement fuel and chemical supplies, their widespread production is unlikely to occur without some impacts on agriculture, other economic sectors and the environment. The magnitude of these impacts will be determined by the extent of and the type of program developed to ensure

sufficient quantities of plant oils being available, if needed. Some of these impacts are identified and discussed qualitatively below.

1. Agricultural and Related Environmental Impacts

Agricultural impacts may occur as modifications to the farming operation, land use including related environmental impacts and use of plant oils for fuel. The impacts also would ultimately include, although they cannot be quantified, the effects on farm prices, net farm income and consumer prices.

a. Modifications to the farming operation

Production of flax, sunflower, safflower, rapeseed, mustard and crambe will require few changes in the present farming operations. Cropping activities for all crops except sunflowers require the same basic operations as wheat and barley. However, some of these crops, especially crambe, will require swathing to avoid seed dispersal before the plant can be combined. This point is not of major importance, however, due to the fact that swathing and subsequent combine pickup equipment is common to many Montana farms, especially where oats are grown. Additional equipment required for cultivation of sunflowers includes combine header attachments which operate by stripping the sunflower head. Additional planting equipment needed for row crops may be necessary although grain drills are sometimes used on farms where row crop equipment is not available. Additional grain drying equipment may also be necessary.

Cultivation of oilseed and oil-bearing crops not currently grown in Montana is not expected to differ substantially from current cultivation activities associated with small grains. Some of the species however, may only be cultivated as row crops with equipment and operational requirements similar to sunflowers.

b. Land use

Widespread production of oilseed and oil-bearing corps would be expected to compete with present food and feed crops for land, unless the oil crops can be grown on set-aside acres or what is now idle or marginal land.

Under the present set aside program, farmers can grow sunflowers and safflowers on set aside acres. If this practice is continued for these and other plant fuel crops, the pressures on and competition for present cropland would be less.

In Montana, cultivation of rangeland and other fragile land has in the past resulted in severe erosion. Some of the previously cultivated land has now been returned to rangeland. An examination of the soils in current range land reveals that if cultivated (Chapter VI), severe erosion could result. An attempt is being made to establish guidelines for cultivating these lands in conjunction with crop insurance. In addition, sections of the SCS manual for Montana deal specifically with this issue. Prior to breaking out of rangeland and other possibly fragile land, serious consideration could be given to requiring an environmental impact assessment, if substantial acreages are involved, to help assure use of proper production technique that would protect against erosion.

Soil erosion from wind could also become a factor in the farmer's decision to grow oilseed crops even on present cropland. Sunflowers, for example, are a row crop and do not provide as good a cover as small grains (Stewart, et al., 1981).

Not all impacts of oil bearing plant production are negative. Beneficial results may occur with the adoption of oilseed crops. The addition of oilseed crops may allow farmers a longer period for planting and harvesting operation. Sunflower, for example, should be planted later in the spring than wheat for best results. Winter rapeseed and flax may provide crops in addition to winter wheat which are sown in the fall. Further research (Bergman and Anderson, 1982; Adolphe, 1980) has indicated that incorporating certain oilseed crops into the cropping rotation can have the beneficial effects of cleaning up grassy,

weed-infested land and also allow for a break in disease and insect pest cycles. Certain crops can also enhance the buildup of crop residues in the soil to improve structure and tilth.

Bergman and Anderson (1982) also suggest that the inclusion of safflower, for example, following small grains rather than fallow could help reduce the spread of saline seep. The cultivation of perennial species, which show promise as oil crops, could also help to reduce the spread of saline seep in areas where it is a problem.

c. Plant oil use

Major problems are associated with burning plant oil in diesel engines which must be overcome for long-term usage. Recent research (ASAE, 1982) indicates increased engine wear can occur with the use of some oil. Gum and carbon buildup is also a problem when burning these oils. These problems may, however, be overcome with modifications to the diesel engines or development of additives for the fuel.

The use of neat vegetable oil and blends is being studied for medium-speed diesel engines by U. S. DOE, the Federal Railroad Administration, and the Association of American Railroads. Medium-speed diesels are used for railroad transportation and electric power generation. The research involves engine testing of neat sunflower oil and blends in 12-cylinder diesels from General Motors and General Electric. The contractor for the study is Southwest Research Institute (SwRI) San Antonio, Texas. These studies indicate that vegetable oil is an acceptable fuel in medium-speed engines and is ready for commercial development.

d. Montana distillate fuel consumption and vegetable oil replacement

Distillate fuel oil consumption in Montana during 1980 and 1981 averaged approximately 275 million gallons annually. Primary users are listed below:

Users	Annual Quantity 1981	1980
	million gallons	
On-highway	100.1	97.2
Railroad	61.1	77.3
Farm	38.1	32.3
Commercial	16.0	12.7
Industrial	16.0	10.1
Oil Company	13.1	6.4
Residential	11.5	15.7
Off-highway	7.7	16.1
Other	8.8	10.5
Total	272.4	278.3

Source: Energy Information Administration, USDOE, Petroleum Supply Annual 1981 Vol. 1, U.S. Government Printing Office, July 1982.

As indicated above, the largest single use of distillate fuel in Montana is on-highway--primarily semi tractor-trailers moving freight. Railroads, which are potential grounds for vegetable oil engine tests are the second largest user of distillate, with average annual consumption of nearly 70 million gallons per year.

It is doubtful that vegetable oil will ever be produced in such a quantity as to replace all distillate fuel in Montana. However the following analysis is presented to illustrate the oilseed acreage which would be required given such a scenario.

The volume of vegetable oil needed to replace a gallon of distillate fuel is uncertain. However, by making the assumption that a gallon of diesel fuel can be replaced by 1.05 gallons of sunflower oil (based on research of fuel consumption and power output by Bettis, et al., 1982), sunflower acreages sufficient to grow enough oil to replace all distillate fuel can be estimated. Given an average sunflower oil yield of 65 gallons per acre, (Table II-5) approximately 4.44 million

acres of sunflowers could produce enough oil to replace the distillate fuel used in Montana. This is approximately 280 times larger than the current Montana sunflower acreage and 1.5 million acres less than the current Montana wheat acreage. To replace the 1981 farm and railroad diesel fuel with sunflower oil would require approximately 1.6 million acres of sunflowers.

e. Other agricultural impacts

Several other problems may develop with the cultivation of certain oilseed crops. Some of the promising species tested, e.g., *Euphorbia esula* (Leafy Spurge) and *Cirsium arvense* (Canada Thistle), are considered weeds which farmers now strive to eradicate. Potential spread from cultivated fields and the length of time residual populations remain in subsequent crop rotation should be studied carefully in conjunction with other cropping feasibility studies. Cultivation of annual and non-rhizomatous perennial species may not be a problem since harvesting would probably occur before seed dispersal occurs. Methods and economics of eradicating residual populations prior to growing subsequent crops need to be examined. Potential diseases and insects problems need to be recognized also. Finally, the potential ecological impact of the introduction of these crops (e.g., influence on wildlife, soil fertility) should be ascertained to the extent possible.

While the adoption of an oilseed crop for producing fuel is not currently feasible, when compared to diesel fuel available at the current price, problems exist in getting any new crop accepted by farmers even if profitable. Farmers may be reluctant to plant a crop which is not a proven producer and for which there is not a well established market. Many experiments on actual farms (as opposed to university agricultural experiment stations) will need to be conducted before the cultivation of oilseed crops will be accepted by Montana farmers. Additionally, in order to have a viable new crop, the simultaneous development of required seeds, agricultural supplies, and crop markets must occur.

2. Economic Impacts

The impacts of plant oil production are not limited to the agricultural sector. Impacts on nonagricultural industries are likely if the cultivation of oilseed crops for fuel becomes widespread. These potential impacts cannot be measured at this time, partially due to the current impracticality of the situation's economics. Examples of these impacts include changes in diesel fuel demand, increases in consumer prices due to the competition for arable land between oilseed crops for fuel and crops associated with food production. Water usage for oilseed processing could also reduce the availability of water for irrigation.

a. Consumer price impacts

Should plant fuel oils be produced in large quantities on current cropland, the supplies of presently grown crops would be expected to decline. The resulting higher farm prices would be expected to be reflected in higher feed, livestock and ultimately meat product prices. The magnitude of such consumer price increase would not be expected to be great unless large acreages of current cropland were devoted to oil-bearing plants.

b. Employment

Not all impacts would be expected to be adverse. It is assumed that plant oil processing will occur in commercial facilities rather than on-farm. Although presently there is excess oilseed processing capacity, with greatly increased production for fuel use, additional processing capacity might be required. Opportunities for additional employment would develop if increased plant oil processing capabilities are required to produce the needed oils.

c. Energy needs

In an overall assessment of the value of plant fuel oils to the energy needs of the state, the energy requirements for production of the plant oils--the field operations, transportation to the processing plant, processing energy and the energy required to produce fertilizers and other agricultural chemicals--would need to be considered. However, if use of the plant oils were confined to emergency situations when diesel fuel supplies are severely limited, the net energy (energy available less energy for production) becomes a less important consideration for the short term.

In summary, the agricultural, other economic and environmental impacts of producing plant oils for fuel depend on the type and extent of program developed.

APPENDIX A

Table A-1. Description of sites sampled

Site	Location	Topography	Soil type	Community type
1	Railroad right-of-way at Three Forks (Old Town)	25% east and west slopes of elevated railroad fill	Gravelly railroad ballast	Railside
2	3 miles east of Bozeman on on Montana 86	4-6% southwest slope Alluvial fan, toe slope		Overgrazed pasture mesic; Festuca idahoensis, Agropyron spicatum
3	Three Forks	Flat (southwest aspect) 1% slope	Silty clay	Sarcobatus vermiculatus, Artemisia tridentata, Agropyron smithii
4	4 miles south of Townsend	Flat (0% slope), aspect roadside and railroad	Gravel	Roadside/railroad
5	6 miles northwest of Augusta on Montana 408	North facing roadside, 15% slope	Gravel	Roadside
6	3 miles east of Fairfield on Montana 408	Southwest, 24% slope	Gravel silt fill	Roadside
7	Freeze Out Lake U.S. 89	Flat (0% slope), 0 aspect	Silt loam	Railroad
8	North Freeze Out Lake	Flat (0% slope), 0 aspect	Silt loan	Railroad
9	1 mile north of Choteau U.S. 89	0% slope, 0 aspect	Gravel	Railroad
10	1 mile north of Choteau on U.S. 89	0% slope, 0 aspect	Gravelly silt loam	Stipa comata, Bouteloua gracilis
11	Dave Stott ranch, 14 miles north of Choteau on Montana 378	0% slope, 0 aspect	Silt loam	Pasture, Agropyron smithii Sitanion hystrix
12	15 miles north of Choteau on Montana 378	0% slope, 0 aspect	Gravelly roadside	Roadside
13	18 miles north of Choteau on Montana 378	Flat (0% slope), 0 aspect	Silt loam	Fallow field
14	1 mile west of Dunkirk on U.S. 2	20% slope, south aspect	Railroad	Railroad
15	20 miles northwest of Fort Benton on Montana 223	5% slope, east aspect	Silt loam, gopher mound	Roadside/wheat field edge
16	58 miles southeast of Great Falls	24% slope, southwest aspect	Silty clay loam	Roadside
17	Wilsall, Montana on east side of main street	2 1/2% slope, east by northeast	Silt loam	Abandoned lot, weeds
18	12 miles south of Musselshell	15% slope, roadside cut south by southeast	Sandy loam soil	Roadside cut
19	14 miles south of Musselshell	5% slope, roadside cut and native range	Sandy loam	Stipa comata Calamovilfa longifolia Yucca glauca
20	12 miles southwest of Musselshell	5% slope, south aspect, roadside cut and native range	Sandy loam	Stipa comata Calamovilfa longifolia Yucca glauca
21	11 miles south of U.S. Fish Hatchery, Fort Keogh on Tongue River floodplain	0% slope, 0 aspect	Silty clay loam	Overgrazed pasture, Stipa comata Bouteloua gracilis

Continued....

Table A-1. (Continued)

Site	Location	Topography	Soil type	Community type
22	10 miles south of U.S. Fish Hatchery, Fort Keogh along roadside-foothills west of Tongue River	Various aspects	Silt loam	Roadside, Artemisia tridentata Stipa comata
23	7 miles south of U.S. Fish Hatchery, Fort Keogh, along roadside, foothills west of Tongue River	5% slope, south aspect	Silt loam	Roadside
24	5 miles south of U.S. Fish Hatchery, Fort Keogh	Southeast aspect	Silt loam	Roadside
25	5 miles west of Forsyth	30% slope, south aspect	Gravelly-loamy sand	Yucca glauca Andropogon scoparius
26	6 miles south of Belgrade	Level floodplain	Shallow soil over gravel	Pasture, Agropyron smithii Stipa comata
27	Cameron Bridge Road 2 miles southeast of Belgrade	Level to nearly level alluvial fan	Deep soil	Abandoned feedlot
28	1 mile East of Logan on U.S. 10	On 30% slope and on level area	Sandy loam	Stipa comata Bouteloua gracilis
29	5 miles north of Three Forks on U.S. 287	5-10% west slope	Calcic roadcut, Regolith	Roadcut
30	5 miles north of Toston	Roadside	Silt loam	Bromus inermis, Poa pratensis
31	1 mile northwest of Three Forks (old town)	1% southwest slope	Silty clay loam	Sacrobatus vermiculatus, Agropyron smithii
32	11 miles northwest of Helena on I-15	5% north slope	Shale road fill	Roadside
33	2 miles north of Wolf Creek on U.S. 287	35% east slope	Roadcut shale	Roadcut
34	5 miles north of Wolf Creek on U.S. 287	2% northeast slope	Roadside shoulder material	Roadside shoulder
35	8 miles north of Wolf Creek on U.S. 287	3% northeast slope	Silt loam	Festuca scabrella, Agropyron spicatum
36	14 miles north of Wolf Creek	5% east slope	Silt loam	Agropyron spicatum, Stipa comata Grazed pasture
37	2 miles south of Augusta on U.S. 287	0% slope aspect	Silt loam	Agropyron spicatum Bouteloua gracilis
38	5 miles east of Augusta on MT 21	0% slope aspect	Roadside fill	Roadside
39	18 miles north of Helena on I-15	30% west slope	Shale roadside cut	Roadside
40	East of Helena on U.S. 287	0% slope	Railroad fill	Railside
41	1 mile north of Winston on U.S. 287	5% west slope	Roadside	Roadside
42	5 miles north of Belgrade on MT 346	5% north slope	Silt loam	Roadside

GLOSSARY 1/

allelopathy - The baneful or harmful influence of one plant on another due to the secretion of toxic substances.

annual - A plant which completes its entire life cycle in one growing season (i.e., from seed to seed). Compare to biennial and perennial.

biennial - A plant which requires at least two years to complete its life cycle, flowering in only the last year of its life. Compare to annual and perennial.

edaphic - Of or relating to the soil; from or influenced by factors inherent in the soil (e.g., salinity, alkalinity or drainage).

flora - 1. A systematic treatise on or a list of plants of an area. 2. Plant life or plants found in a particular area (e.g., Montana).

genus - A taxonomic category, ranking between the family and the species and comprising a group of structurally or phylogenetically related species.

herbarium - A room or building housing a collection of dried plant specimens usually mounted and systematically arranged for botanical reference.

perennial - A plant that lives for an indefinite number of years and flowers more than once during its lifetime.

pericarp - Tissue, surrounding seeds, that originates from the walls of the plant ovary. This tissue can be fleshy (e.g., apple, berry), hard or bony (e.g., nuts, sunflowers) or membranous (e.g., peapods).

species - A category of biological classification ranking immediately below a genus or subgenus; a group of intimately related and physically similar organisms that actually or potentially interbreed and are less commonly capable of fertile interbreeding with members of other groups...

1/ Definitions appropriate to the use of glossary words (in this report) were selected from Merriam Webster, Webster's Third New International Dictionary of the English Language, Unabridged, (Chicago: Encyclopedia Britannica, Inc., 1971).

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